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GEORGE OTIS SMITH, DIRECTOR

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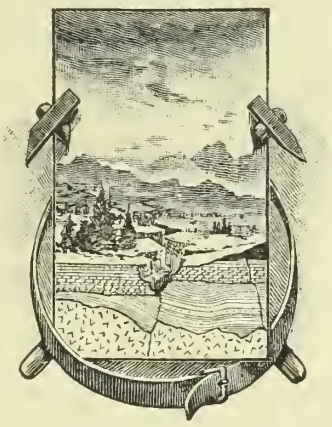

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 371

RECONNAISSANCE

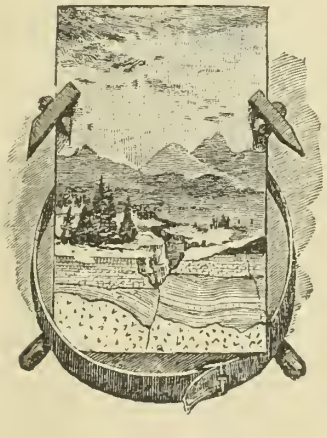
OF THE

BOOK CLIFFS COAL FIELD

BETWEEN GRAND RIVER, COLORADO
AND SUNNYSIDE, UTAH

BY

G. B. RICHARDSON



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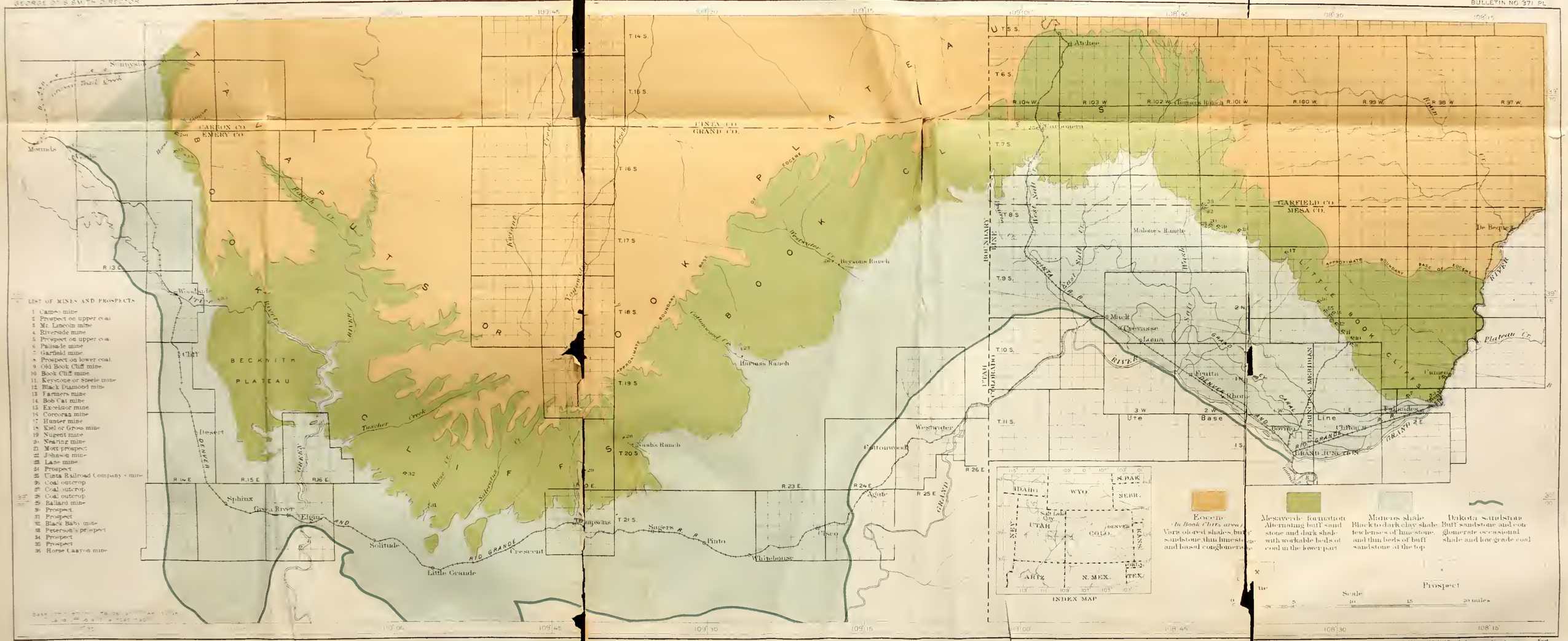


RECONNAISSANCE MAP AND [illegible] SECTION OF PART OF THE BOOK CLIFFS COAL FIELD, COLORADO AND UTAH

By G. B. Richardson and L. J. Pepperberg, 1906

RECONNAISSANCE MAP AN

RECONNAISSANCE OF THE BOOK CLIFFS COAL FIELD, BETWEEN GRAND RIVER, COLORADO, AND SUNNYSIDE, UTAH.

By G. B. Richardson.

INTRODUCTION.[a]

The Book Cliffs coal field is part of the southern rim of the Uinta Basin, which is an immense structural trough in western Colorado and eastern Utah, around whose margin the outcrop of coal-bearing rocks can be traced for more than 500 miles. (See fig. 1.) From the vicinity of Mount Hilgard, in central Utah, northward to Castlegate, the coal measures form the eastern escarpment of the Wasatch Plateau. Thence they trend southeastward to Grand River, outcropping in the Book Cliffs. Beyond Grand River they continue eastward, forming the southern face of Grand Mesa, to the vicinity of Crested Butte. From this point the coal-bearing rocks trend northward and cross Grand River again near Newcastle. North of Grand River they form the Grand Hogback, and beyond the Danforth Hills the trend is westward along the southern flank of the Uinta Mountains. This great basin of coal-bearing rocks has been but partially prospected, and mines are in operation in only a few localities, but enough of the area has been explored to prove that it is one of the most important coal reserves of the Rocky Mountain region. As a whole, this area is a distinct unit, but for convenience of study and description, it is divided into several parts. The Book Cliffs field is that portion of the southern rim of the Uinta Basin which includes the Book Cliffs and lies between Grand River, Colorado, and the Wasatch Plateau, Utah.

The geology of the Book Cliffs was first studied by A. C. Peale,[b] of the Hayden Survey, who in 1876 examined the eastern part of the field. The western part was included in G. H. Eldridge's map of the Uinta Basin published in connection with his study of asphalt and bituminous rock deposits.[c] Until recently these papers have

[a] An abstract of this report was printed in Contributions to Economic Geology, 1906, Part II: Bull. U. S. Geol. Survey No. 316, 1907.

[b] Peale, A. C., Geological report on the Grand River district: Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, pp. 170–185.

[c] Eldridge, G. H., Asphalt and bituminous rock deposits of the United States: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 1, 1901, p. 332.

been the only available systematic geologic reports of the region. The presence of coal in the Book Cliffs has long been known. The deposits are mentioned by R. C. Hills[a] in his report on the coal fields of Colorado, and by L. S. Storrs[b] in his paper on the Rocky Mountain coal fields. Arthur Lakes has also referred to part of the area[c] and has described the Book Cliff mine.[d] But the coal field was not examined in detail until 1905, when J. A. Taff,[e] of the United States Geological Survey, studied the western part of the field from the vicinity of Sunnyside to Castlegate, Utah, and its southern continuation along the escarpment of the Wasatch Plateau.

During three months of the season of 1906 the writer, assisted by W. D. Neal, L. J. Pepperberg, and C. D. Perrin, made a reconnaissance survey of the eastern part of the Book Cliffs field from Grand River westward to the termination of Taff's work. The attention of the party was devoted mainly to a study of the occurrence of the coal. The boundary between the Mancos shale and the Mesaverde formation—the most easily recognized horizon nearest the coal—was followed throughout the field, but in the time available detailed mapping of the formations could not be attempted. The location of the Dakota sandstone outcrop below the Mancos shale and the position of the base of the Eocene above the Mesaverde formation were determined only at certain localities, and the boundary between these formations, shown on Plate I by a dotted line, is only approximately located.

TOPOGRAPHY.

The Book Cliffs form the southern margin of the Book or Tavaputs Plateau, which is situated in the central part of the Colorado Plateau province, between the Rocky Mountains and the Wasatch Range. The southward-facing cliffs, which extend in a great east-west line from Grand River to Castlegate, lie north of and generally in sight of the Denver and Rio Grande Railroad and are one of the most striking topographic features along that railroad. The cliffs do not form an unbroken wall, but locally are deeply cut by small streams into a series of spurs which, although much lower than the main mass of the plateau to the north, tower above and dominate the great plain at their base. This plain is eroded in the soft shale underlying the coal-bearing rocks, and it affords a route for the railroad which closely skirts the foot of the cliffs throughout most

[a] Hills, R. C., Coal fields of Colorado: Mineral Resources U. S. for 1892, U. S. Geol. Survey, 1893, p. 353.

[b] Storrs, L. S., The Rocky Mountain coal field: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, p. 436.

[c] Lakes, Arthur, The Grand River coal field: Mining Reporter, vol. 51, 1905, pp. 379–381.

[d] Lakes, Arthur, The Book Cliffs coal mine: Mines and Minerals, vol. 24, 1904, pp. 289–291.

[e] Taff, J. A., The Book Cliffs coal field: Bull. U. S. Geol. Survey No. 285, 1906, pp. 289–302.

of their extent. South of this broad valley stratigraphically lower and harder rocks are exposed in the Uncompahgre Plateau and the

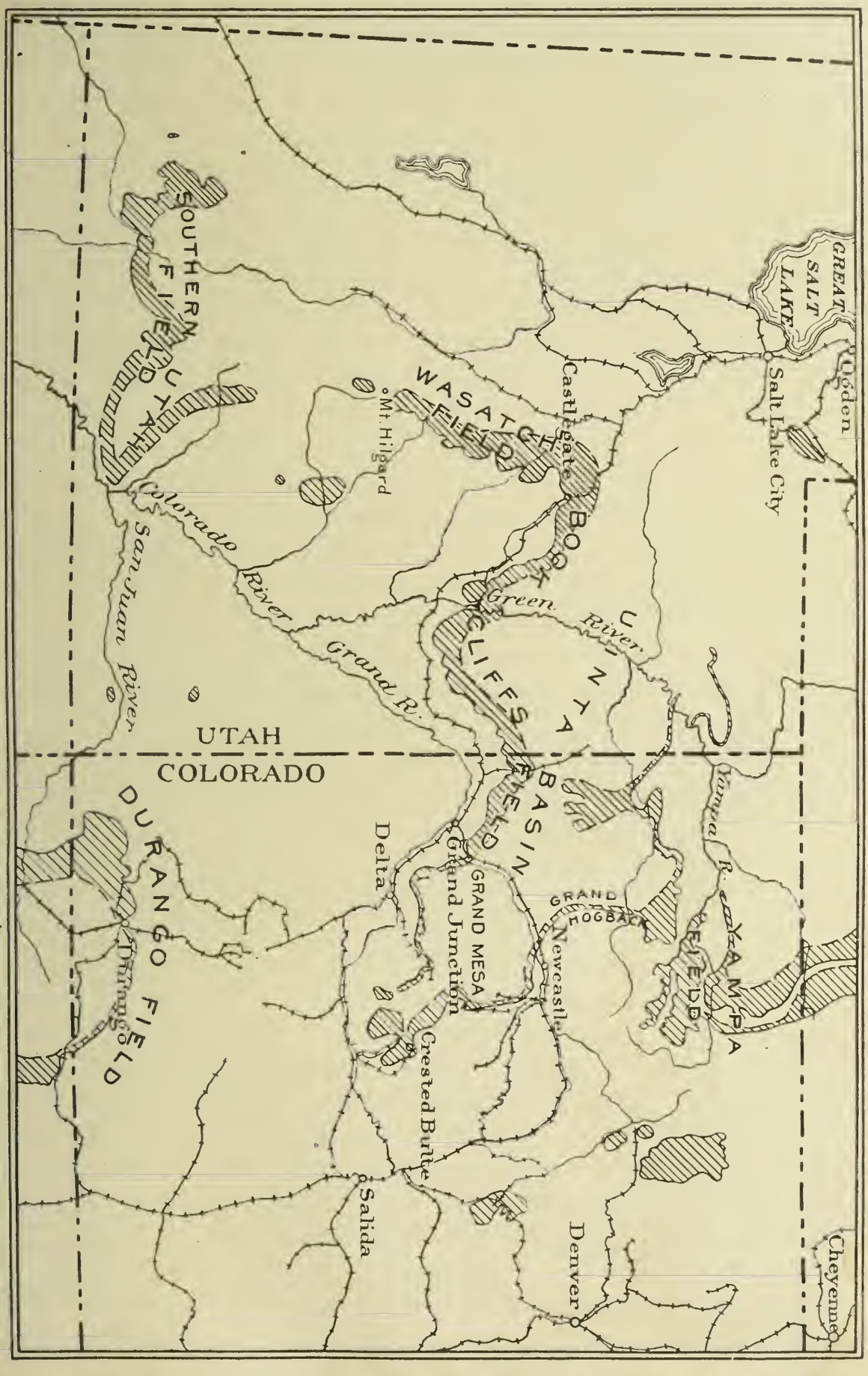


FIGURE 1.—Map showing relation of the Book Cliffs field to adjacent coal fields.

San Rafael Swell, two great anticlinal uplifts south of the Uinta Basin.

RELIEF AND DRAINAGE.

The altitude of the surface throughout the Book Cliffs field ranges from about 4,000 feet in the lowlands to 8,000 and 9,000 feet above sea level on the plateau. The area is drained by Green and Grand rivers, which unite to form the Colorado about 60 miles south of the Book Cliffs.

Green River, after leaving the Uinta Mountains, flows in a southwesterly direction across the Uinta Basin and cuts through the Tavaputs Plateau in a steep, narrow gorge known as "Desolation Canyon." At the mouth of the canyon in the Book Cliffs the stream emerges into the lowlands, where it meanders in a broad valley for 10 or 12 miles. It flows across the belt of lowland and enters another canyon on its way to its junction with the Grand. Green River receives a number of large tributaries in the Uinta Basin—Yampa and White rivers on the east and Uinta and Duchesne on the west; but in its canyon course through the Tavaputs Plateau the only important branch is Price River, and in the lowland south of the Book Cliffs there is no addition to its flow. East of Desolation Canyon the plateau drains northward by Kwiant and Yogowotsi creeks, which, rising near the rim of the Book Cliffs, enter the river a few miles below the mouth of White River.

Price River rises on the Wasatch Plateau, flows southeastward, and emerges from the canyon it has cut in the plateau at Castlegate. Thence it flows along the broad lowland valley at the base of the Book Cliffs for a distance of 25 miles. Instead of continuing in the lowland, however, it crosses the northern end of the San Rafael Swell, flows directly across the lowland valley again, cuts a deep canyon which separates Beckwith Plateau from the Tavaputs Plateau, and finally enters Green River about 6 miles above the mouth of Desolation Canyon.

Grand River, rising near the Continental Divide, on the Front Range of the Rocky Mountains, in Middle Park, Colorado, flows southwestward and enters the area under consideration at the mouth of Roan Creek in a relatively broad valley. A few miles below Roan Creek the river enters Hogback Canyon, in which it flows through the Little Book Cliffs and emerges into the lowland immediately above the town of Palisades. The river crosses the lowland, a distance of about 13 miles, to the town of Grand Junction, where it is joined by Gunnison River. The Grand then turns abruptly northwestward and follows the southern margin of the lowland for 18 miles. Below Fruita it leaves the lowland, and again flowing southwestward cuts across the northern end of the Uncompahgre Plateau, and continuing southwestward, mostly in a canyon course, finally joins the Green.

With the exception of the Gunnison, Grand River receives no large tributaries in the Book Cliffs field. The most important is Roan

Creek, which drains the area between the Little Book Cliffs and the Book Plateau northwest of De Beque. The streams which flow southward from the Book Plateau are small, and on account of the slight precipitation and limited drainage area flow intermittently throughout the year. During the dry months the discharge even within the highlands almost ceases and the stream beds across the lowlands are dry.

The relation of the through-flowing streams to the lowland indicates that their general courses were defined before the development of the present topography, for there is little adjustment between the drainage and the outcrops of the hard and soft formations. Grand River conforms only partially with the trend of the lowland; Green River maintains its way directly across the shale belt; Price River, flowing alternately over hard and soft rocks, instead of continuously in the shale lowland, is a good example of superimposed drainage.

LOWLAND AT BASE OF BOOK CLIFFS.

The lowland at the base of the Book Cliffs extends in a curved but general westerly direction from Palisades, Colo., to Helper, Utah, a distance of 190 miles. From Palisades it continues southeastward between the Uncompahgre Plateau and Grand Mesa, and from Helper the lowland extends southward between the San Rafael Swell and the Wasatch Plateau, where it is known as Castle Valley. Throughout its extent the lowland is underlain by shale and is not a stream valley in the sense of being carved and occupied by a single master stream; instead, the lowland has been eroded in soft rock by general subaerial action and forms part of several drainage basins. The lowland has been widened by the gradual recession of the Book Cliffs northward due to the weathering of the soft shale and the undermining of the overlying hard sandstone which forms the cliffs. By this process the cliffs have retreated, but they have maintained a fairly regular front.

The average width of the lowland is about 12 miles, having a maximum of 23 miles, in the vicinity of Cisco, and a minimum of 4 miles, near Woodside. The lowland is an undulating plain that rises gently toward the bordering highlands and extends between the Book Cliffs on the north and a belt of sandstone hills on the south. It practically coincides with the outcrop of the Mancos shale. The small streams that head in the Book Cliffs and cross the lowland have carved steep arroyos, which impede travel. In the vicinity of the cliffs there are outlying buttes and the shale is eroded into badlands. Adjoining the cliffs there are local fringing remnants of an old outwash gravel-covered plain into which the streams have cut their way 100 feet or more, and south of Grand River, near Palisades, a number of terraces are well developed. The largest, about 150 feet above the river, is

between a quarter and a half mile wide, and traces of several other less distinct terraces have been found above this one.

BOOK CLIFFS.

The Book Cliffs occupy a belt from 1 to 10 miles wide and rise above the adjacent lowland from 2,000 to 6,000 feet. In places the rise is abrupt in one or two sharp precipices; elsewhere it is accomplished by a series of cliffs and intervening benches. The rocks composing the escarpment are alternating beds of sandstone and shale dipping slightly northward, and the strata present the appearance of the leaves of a book lying flat, hence the name.

In the area here discussed the cliffs extend in an S-shaped belt from Palisades to Sunnyside. At the east they are much dissected by Roan Creek, and a subordinate escarpment known as the Little Book Cliffs extends northwestward from the mouth of Hogback Canyon. The top of the Little Book Cliffs marks the crest of a ridge whose northeastern flank constitutes a dip slope, and the area between Little Book Cliffs and Roan Creek is a gentle northeastward-sloping monocline dissected by southeastward-flowing streams.

West of the headwaters of Roan Creek the Book Cliffs proper extend to the end of the area mapped. Erosion by East and West Salt creeks has caused the rim of the plateau to recede so much that a few miles east of the Utah-Colorado boundary the distance between the lowlands and the plateau is unusually great. Between the State line and Green River the average distance is about 10 miles. Here a low bench, caused by a great lens of sandstone in the shale, forms the base of the cliffs, as shown in Plate II, *A*. Above this lowest bench there is a succession of dissected platforms and escarpments up to the summit of the plateau.

Green River has cut another embayment in the cliffs, and Price River in its canyon course separates a small area, known as the Beckwith Plateau, from the main mass of the upland. The Beckwith Plateau is considerably dissected on the north and east, but faces the lowland on the west in a practically unbroken scarp more than 1,500 feet high. Beyond Price River a similar line of cliffs extends at least as far as Sunnyside. The surface at the summit of this cliff slopes eastward and forms a platform upon which another but more dissected line of cliffs rises 1,500 feet higher.

BOOK OR TAVAPUTS PLATEAU.

The crest of the Book cliffs forms the southern rim of the Book Plateau, or, as it is known in Utah, the Tavaputs Plateau, which viewed from the south, forms an even-topped sky line. The plateau slopes gently northward toward the axis of the Uinta Basin, but is much dissected by deep canyons.

A. BENCH AT BASE OF BOOK CLIFFS, EAST OF THOMPSONS.

B. FAULT IN MESAVERDE FORMATION, 2 MILES SOUTH OF CARBONERA.

CLIMATE AND CULTURE.

The climate of the region is arid, the mean annual rainfall at Grand Junction being only 7.8 inches. The vegetation, therefore, is of the desert type, and the shale lowland in its natural state is practically bare or yields a meager growth of desert plants. The uplands receive more rain and support stunted conifers, oaks, etc. In general, timber suitable for mining purposes is scarce. In the Grand Junction region timber for this purpose is imported, but in the western part of the field it is more plentiful. In the valleys where irrigation is practiced the desert has been converted into a garden, and portions of the area rival in productiveness any part of the country. The mean annual temperature is 53°, the summers being warm and the winters usually mild. The percentage of sunshine is 75 and general climatic conditions are delightful. In the irrigated areas contiguous to Grand, Green, and Price rivers there are a number of thriving settlements where fruit growing is an important industry. Grand Junction, the most important place in the field, is a typically progressive western town. The lowland is traversed in an east-west direction by the main line of the Denver and Rio Grande Railroad.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

The general sequence of formations in the coal fields of the Uinta Basin, as determined by recent work of the United States Geological Survey,[a] is shown in the following table:

Geologic formations in Uinta Basin.

System.	Series.	Formation.
Tertiary.	Eocene.	Green River formation. Wasatch formation. Fort Union or older (?).
	Unconformity.	
Cretaceous.	Upper Cretaceous.	Mesaverde formation. Mancos shale. Dakota sandstone.
	Unconformity.	
Jurassic.		

To the subdivisions of the Cretaceous are given the names introduced by Whitman Cross for southwestern Colorado.[b] This classi-

[a] Taff, J. A., Pleasant Valley coal district, Utah, and Gale, Hoyt S., Coal fields of the Danforth Hills and Grand Hogback, Colorado: Bull. U. S. Geol. Survey No. 316, 1907.

[b] Cross, Whitman, La Plata folio (No. 60), Geologic Atlas U. S., U. S. Geol. Survey, 1899.

fication differs from that of Peale, of the Hayden Survey, who in his report on the Book Cliffs field[a] separated the rocks here assigned to the Mesaverde formation into the "Fox Hills" and the "Laramie." It was recognized by the Hayden Survey that there is no distinct lithologic break in the Book Cliffs between the "Laramie" and the "Fox Hills," and the nomenclature employed was an attempt to conform to subdivisions used in other fields. It has been found desirable, however, to restrict the use of the name "Fox Hills" to the original area in South Dakota,[b] and, as shown below, these rocks are not Laramie, but belong in the Montana group. The classification here adopted is based on the general stratigraphic and areal relations of the rocks and on fossil evidence, as explained on pages 17–19. The Uinta Basin section differs from that of southwestern Colorado and the Yampa coal field in northwestern Colorado[c] by the absence of the Lewis shale and the Laramie formation between the Mesaverde and the Eocene. This hiatus in the Book Cliffs field appears to be accounted for by the unconformity at the base of the Eocene, which implies that these formations, if they were ever present in the area under discussion, were removed by erosion previous to the deposition of the overlying Tertiary rocks.

In the Book Cliffs field the general character and sequence of the rocks is shown by the section in Plate III. The strata are separable into four distinct lithologic divisions, the three Cretaceous formations named and the Eocene rocks, all easily recognizable throughout the field by their physical character and sequence.

CRETACEOUS SYSTEM.

DAKOTA SANDSTONE.

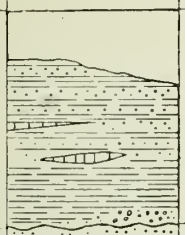
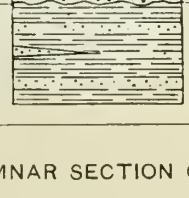
The Dakota sandstone in the area here considered possesses the characteristic features common to the formation in this general region. It is composed of buff quartzitic sandstone, generally conglomeratic, and local beds of carbonaceous shale and low-grade coal are provisionally included in the formation, although no fossils have been found in them in the Book Cliffs field. The Dakota varies in thickness from about 200 feet to less than 25 feet. The outcrop forms a narrow belt of low hills parallel to and about 12 miles south of the Book Cliffs.

The formation is extremely variable in composition and arrangement of the beds, as shown by the following sections measured in different parts of the field. At the mouth of Gunnison River, south of Grand

[a] Peale, A. C., Geologic report on the Grand River district: Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878.

[b] Stanton, T. W., Geology and paleontology of the Judith River beds: Bull. U. S. Geol. Survey No. 257, 1905, p. 66.

[c] Fenneman, N. M., and Gale, Hoyt S., The Yampa coal field: Bull. U. S. Geol. Survey No. 297, 1906.

AGE.	FORMATION.	SECTION.	THICKNESS, IN FEET.	DESCRIPTION.
Eocene.	Mostly Wasatch.		500+	Varicolored shales, buff sandstone, local basal conglomerate, and subordinate thin beds of limestone containing fresh-water shells. Different sections show diverse stratigraphy. These rocks form the highest cliffs and constitute the floor of the Uinta Basin.
	Unconformity			
Upper Cretaceous.	Mesaverde.		1,200 to 2,200	Alternating beds of buff sandstone and drab shale with workable beds of coal in the lower part of the formation. Fossils occur at several horizons, including leaves, invertebrates, and occasional bones. These are the cliff-making rocks of the Book Cliffs.
	Mancos shale.		3,000±	Fissile black to drab clay shale and local lenses of limestone. Thin beds of buff sandstone at the top mark the transition to the overlying formation. Marine shells are abundant at two general horizons in the upper and lower parts of the formation. This shale underlies the broad lowland at the base of the Book Cliffs.
	Dakota sandstone.		25 to 200	Buff sandstone, often conglomeratic.
	Unconformity			
Jurassic?.	Morrison.		300+	Red, green, and purple shales with lenses and thin beds of buff sandstone containing dinosaur bones.

GENERALIZED COLUMNAR SECTION OF THE ROCKS OF THE BOOK CLIFFS COAL FIELD.

Junction, the following measurements were made, but no Dakota fossils were found, and the limits of the formation were not determined:

Section of strata south of Grand Junction.

	Feet.
Shale, drab (Mancos)	5
Sandstone, buff, lens (Dakota?)	
Shale, carbonaceous, containing thin layers of coal (Dakota?)	20
Sandstone, massive, cross-bedded, cream-colored, quartzitic, including irregular lenses of conglomerate with rounded pebbles of chert and quartzite up to 1 inch in diameter (Dakota)	20
Shale, drab, probably below Dakota	1
Sandstone, greenish drab, shaly	2
Shale, greenish drab	20+
	68

Between Grand Junction and Fruita the outcrop of the Dakota lies immediately south of Grand River, but the formation is covered by sand and gravel at many places. In this locality the carbonaceous shale is well developed, and at several places there are coal prospects. In a creek about midway between Grand Junction and Fruita the following section is exposed:

Section of Dakota (?) coal beds in creek midway between Grand Junction and Fruita.

	Ft.	in.
Sandstone, buff	4	
Shale, carbonaceous	2	
Coal	1	6
Shale, carbonaceous	1	
Coal (varies from 2 to 3 feet)	2	6
Shale, carbonaceous		6
Coal		8
Shale, carbonaceous		8
	12	10

The formation crosses the river west of Fruita and the following section was measured south of Loma:

Section of Dakota sandstone south of Loma.

	Feet.
Shale, dark with local carbonaceous layers (Colorado).	
Sandstone, buff, including thin layers of shale and lenses of conglomerate with pebbles of chert and quartzite	40
Shale, greenish, sandy	50
Sandstone, buff, and conglomerate	25
Sandstone, white	20
Shale, varicolored (Jurassic).	
	135

South of Thompsons, Utah, there are 100 feet of massive white and buff sandstones, cross-bedded and locally conglomeratic, lying between drab shale above and varicolored shale below. At this place the carbonaceous beds seem to be absent, and they were not found farther

west in the area examined. Near Green River the formation is variable. In places south of Elgin the sandstone thins out to a few feet and locally disappears, while nearby it thickens to 40 feet or more. Some exposures show considerable conglomerate, while others show but little conglomerate and much sandstone.

Characteristic Dakota leaves were found in the sandstone near Elgin and in the vicinity of Woodside. They were examined by F. H. Knowlton, who furnishes the following lists:

Dakota fossils from Woodside.

Laurus proteæfolia Lesq.
Laurus modesta? Lesq.

Dakota fossils from Elgin.

cf. Pecopteris striata Heer, from the Unter Atanekerdluk (Cenomanian) beds of Greenland.
Gleichenia sp.?
Torreya oblanceolata Lesq.
Pinus sp. (cone scales).
Liquidambar integrifolium Lesq.
Andromeda linearifolia? Lesq.
Salix proteæfolia Lesq.

The Dakota sandstone is underlain by several hundred feet of red, green, and purple shales with intercalated layers of buff sandstone and thin blue limestone. A number of dinosaur[a] bones have been found in these beds, which probably represent the Morrison formation. The contact between the Cretaceous (Dakota) and Jurassic is not everywhere distinct, but in several localities the former is exposed lying unconformably on an undulating surface of varicolored Jurassic shale.

MANCOS SHALE.

The Mancos shale forms the base of the Book Cliffs (Mount Garfield, Pl. IV), where it is sculptured into badland topography, and it underlies the broad valley between the cliffs and the hills of Dakota sandstone to the south. It is a fissile black, blue-gray, and drab clay shale, which contains local lenses of limestone, and, at the top, thin beds of buff sandstone. The shale constitutes a distinct lithologic unit in which there is little variation, though the color of the lower part is generally darker than the upper. It is much broken by cracks and joints, which frequently contain thin saline films. These locally effloresce in patches of white powder, some of which were found to consist chiefly of calcium carbonate, and the unreclaimed areas of shale are characteristically coated with "alkali." Lenses of blue-gray fossiliferous limestone, from several inches to a few feet in thickness,

[a] Riggs, E. S., The dinosaur beds of Grand River valley, Colorado. Field Columbian Mus. geol. series, vol. 1, 1901.

MOUNT GARFIELD, 9 MILES EAST OF GRAND JUNCTION.

Shows weathering of Mancos shale at the base of Book Cliffs. The "lower coal" occurs beneath the massive sandstone.

occur at several horizons, but chiefly in the upper few hundred feet of the formation. This part of the formation is also characterized by beds of buff sandstone, usually thin bedded, by which the Mancos shale grades into the overlying Mesaverde formation.

From the nature of the exposures the thickness of the Mancos shale is difficult to determine. The best measurement was obtained from a drill hole near the upper terminus of the Book Cliffs Railroad, about 10 miles northeast of Grand Junction. This began about 200 feet below the top of the formation, and was still in shale when drilling was stopped at a depth of 2,600 feet, showing a minimum thickness of 2,800 feet. The dip of the shale in the valley can be only roughly estimated; but assuming an average of 2° and allowing 1,200 feet for the difference in elevation between the outcrops of base and top of the shale, and a width of outcrop of 11 miles, gives a thickness of about 3,200 feet.

Marine shells have been found in the shale at two general horizons, one near the base and the other near the top. The lower collections were obtained at several localities within 200 feet of the base of the formation, and among these T. W. Stanton has identified the following forms:

Fossils from lower part of Mancos shale.

Anomia sp.
Modiola sp.
Ostrea lugubris Conrad.
Inoceramus dimidius White.
Inoceramus fragilis H. and M.
Scaphites warreni M. and H.
Prionocyclus macombi Meek.
Callista sp.
Pyropsis? sp.
Baculites gracilis Shumard?
Gryphæa newberryi Stanton.

Most of the fossils from the upper part of the shale were found in limestone lenses about 250 feet below the lowest coal bed, but a few specimens were obtained in sandstone only 50 feet below the coal. They include the following forms, identified by T. W. Stanton:

Fossils from upper part of Mancos shale.

Lucina sp.
Baculites compressus Say.
Baculites ovatus Say.
Inoceramus cripsi var. barabini Morton.

Concerning these fossils Stanton reports as follows:

The fossils of the shale between the Dakota and the coal-bearing rocks indicate that two distinct faunas are represented, one, in the lower part, being characteristic of the Benton shale of the Colorado group, and the other, near the top, equally characteristic of the Montana group. As this agrees perfectly with the fauna of the Mancos shale in the type locality, and as there is also essential agreement in other respects, such as stratigraphic position, lithologic character, and thickness, it seems justifiable to apply the name Mancos to this shale.

MESAVERDE FORMATION.

Well-exposed sections in the face of the Book Cliffs (Pls. IV and X) show that the Mancos shale grades upward into the overlying Mesaverde formation with no apparent break in sedimentation. The transition is marked by the increasing prevalence of sand in the upper part of the Mancos, and in the Book Cliffs field a sharp boundary can not be drawn between the formations. The Mesaverde consists of alternating beds of buff sandstone and drab or dark shale with workable beds of coal in the lower part (Pl. V). These are the escarpment-making rocks of the Book Cliffs, and they are well exposed throughout the area.

The sections in Plate VI show the general character of the formation. About a third of it is composed of shale, most of which occurs in the lower half, while the upper part consists principally of sandstone. The areal distribution of the different strata is varied, and no two sections are exactly alike. Some beds of sandstone, however, are persistent for several miles. Coal is practically limited to the lower 700 feet of the formation, and throughout the field one or more beds ranging from 2 to 21 feet thick have been found, as described on pages 24–41, wherever prospecting has been done. The shale of the Mesaverde formation is commonly sandy and is drab in color, but where associated with the coal it is usually carbonaceous. The sandstone is generally buff, though occasionally it is almost white, and in places red. The bedding ranges from thin to massive, some of the layers being only a few inches while others are 50 feet thick, the usual thickness being between 2 and 5 feet. The sandstone is prevailingly fine textured and is conspicuously feldspathic, consisting in general of rounded grains of quartz with considerable feldspar and subordinate mica. Exposed surfaces are often coated with efflorescing salts, and the sandstone locally shows honeycomb weathering. The rocks of the Book Cliffs coal field are traversed by numerous joints, which are prominently developed in the sandstone. Two sets, at right angles, are commonly present.

At many places in the lower part of the formation the sandstone is distinctly red. The color is distributed in irregular patches, generally, if not always, a few feet above a coal bed, and usually at exposed jutting outcrops. There appears to be no difference in general composition between the normal buff sandstone and that colored red, and the distribution of the highly colored rocks is too irregular to be accounted for by differences in original deposition. Similar occurrences have been reported from several of the Rocky Mountain coal fields, and the color is believed to be due to the burning of coal in underlying beds, the formation of the color being analogous to that in the burning of bricks. In Horse Canyon, at the western limit of the present survey, the coal bed is about 16 feet

A. TYPICAL EXPOSURE OF MESAVERDE FORMATION, 25 MILES NORTH OF THOMPSONS.

B. OUTCROP OF COAL IN VALLEY OF SALERATUS CREEK.

thick and is normally overlain by buff sandstone. But south from the prospect near the mouth of the canyon, on the west side, the coal locally disappears and its place is occupied by a thin deposit of whitish, ashlike material about a foot thick, and the overlying thin-bedded red sandstone is crumpled and broken, as if it had fallen consequent to the burning of the coal. Bits of slaglike material, clinkers, etc., are in the vicinity.

The thickness of the coal-bearing formation is variable and decreases toward the west. Immediately east of Grand River the entire formation is exposed in steep cliffs, and a thickness of 2,200 feet was measured barometrically on the flanks of Grand Mesa. North of Thompsons, Utah, a thickness of about 1,800 feet was measured, but an allowance for dip makes this measurement less reliable. At the mouth of Horse Canyon, in the west end of the field, the formation is only about 1,200 feet thick. As stated on page 19, the erosion of the Mesaverde before the deposition of the overlying Tertiary rocks is probably the cause of the observed difference in thickness.

Fossils occur in this formation at several horizons and include invertebrates, leaves, and a few bones. Shells were found in many localities between 200 feet above the lowest coal bed and 250 feet below the overlying varicolored deposits. Among the fossil shells Stanton has identified the following species:

Fossils from Mesaverde formation.

Ostrea sp.
Ostrea glabra M. and H.
Anomia gryphorhynchus Meek.
Anomia micronema Meek.
Modiola laticostata White?
Modiola cf. regularis White.
Unio, several species.
Corbula perundata M. and H.
Corbula subtrigonalis M. and H.
Corbicula cytheriformis M. and H.
Campeloma? sp.
Tulotoma thompsoni White.
Goniobasis sp.
Molluscan burrows in fossil wood.

A number of small lots of fossil leaves were collected from this formation at several localities, and at a few places fairly good collections were obtained, which were identified by F. H. Knowlton as follows:

About a quarter of a mile northwest of the present Book Cliff mine, from a sandstone 30 feet above the upper coal, the following were collected:

Fossil leaves from sandstone near the Book Cliff mine.

Sequoia Reichenbachi (Gein.) Heer.
Eriocaulon? porosum Lesq.
Palm (new).
Ficus latifolia (Lesq.) Knowlton.
Myrica Torreyi Lesq.
Magnolia sp.

Near the mine entry several specimens of *Halymenites major* Lesq. were obtained.

Three-fourths of a mile northwest of Cameo, about 100 feet above the upper coal, a narrow leaf, apparently *Salix, Sequoia Reichenbachi*? (Gein.) Heer, and fragments of dicotyledons were found.

Fifty feet above Ballard's coal mine north of Thompsons *Anemia elongata* (Newb.) Knowlton and *Myrica Torreyi* Lesq. were found.

About 200 feet above the coal at Carbonera fragments of dicotyledons, including *Myrica Torreyi*? Lesq., were found.

About 8 miles north of Thompsons, 250 feet below the conglomerate which is regarded as marking the base of the Eocene, the following were obtained:

Fossil leaves from a locality about 8 miles north of Thompsons.

Sequoia Reichenbachi (Gein.) Heer.
Sabalites Grayanus? Lesq.
Ficus planicostata Lesq.
Cinnamomum affine? Lesq.
Malapoenna new.
Ficus sp., very large, apparently new.
Dicotyledon, very large, with three ribs, prominent teeth, etc., probably new.

The only fossil bones from this formation were obtained east of Green River, about 500 feet above the top of the Mancos shale. They were determined by J. W. Gidley, of the United States National Museum, to be the distal ends of femurs of a dinosaur.

There has been much misapprehension concerning the age of the coal-bearing rocks of the Uinta Basin. In the Book Cliffs field, as already stated, Peale mapped the rocks here referred to the Mesaverde as two formations and correlated them respectively with the "Fox Hills" and the "Laramie." Later writers have considered the entire formation to be Laramie, because it overlies marine Cretaceous beds and in turn is overlain by Wasatch strata, and the fauna and flora were believed to belong to the Laramie.

Just what constitutes the Laramie has long been a problem with geologists, but recent studies of the Rocky Mountain coal fields by the United States Geological Survey have thrown new light on the subject. The reason for assigning the coal-bearing formation of the Book Cliffs to the Mesaverde is explained in the following extract from a letter of T. W. Stanton to the writer, reporting upon fossils collected from this field.

In northwestern Colorado, southern Wyoming, and elsewhere, many of the coal-bearing rocks previously called Laramie are really older and are overlain by marine Cretaceous formations, thus corresponding with the Mesaverde formation first described in southwestern Colorado. The Mesaverde formation has been identified in the Yampa field, where the stratigraphic evidence is satisfactory that it underlies a thick marine Cretaceous formation, correlated with the Lewis shale, which in turn is overlain by the Laramie and later formations. South of the Yampa field, in the Danforth Hills and the Grand Hogback, the Mesaverde is clearly recognizable, but here there is an erosional unconformity which cuts out the Lewis and the Laramie and brings the Mesaverde in contact with the Fort Union[a] and possibly later formations.

[a] Gale, H. S., Coal fields of the Danforth Hills and Grand Hogback in northwestern Colorado: Bull. U. S. Geol. Survey, No. 316, 1907, pp. 264-301.

The invertebrate fauna of the Mesaverde includes two distinct elements; one consisting of marine species is found chiefly in the lower portion, sometimes in beds alternating with those containing the other, which consists of fresh-water and brackish-water forms. The marine element is a direct continuation of the upper Mancos fauna and is not safely distinguishable from it without full stratigraphic data. The nonmarine fauna is closely related to that of the Laramie, with which it has some species in common, especially in the genera *Ostrea* and *Corbicula*. During the past season [1907] the fact has been established that *Tulotoma thompsoni*, hitherto regarded as a characteristic Laramie species, occurs in both the Laramie and the Mesaverde.

The invertebrate fossils that have been collected from the coal-bearing rocks of the Book Cliffs all occur in the Mesaverde of northwestern Colorado, and Doctor Knowlton finds that this is essentially true of the plants also. It is admitted that most of the fossils in question from the Book Cliffs would not seem out of place in the Laramie, yet their close agreement with those known to occur in the Mesaverde of a neighboring area, and the general stratigraphic and areal relations of the rocks in which they are found, make their reference to the Mesaverde most reasonable. The unconformable relations that doubtless exist between those rocks and the overlying Wasatch will explain the absence of the later Cretaceous rocks from the area.

In the Book Cliffs field the unconformity between the Mesaverde and the overlying Eocene is marked not only by the absence of the Lewis shale and the Laramie, but also by the westward thinning of the Mesaverde formation (p. 17), by the basal Eocene conglomerate, and by the distinct general difference in stratigraphy between the underlying buff sandstones and shales, which are brackish-water and fresh-water deposits, and the overlying variegated formation which accumulated under more diverse conditions, probably in part subaerial and in part lacustrine.

TERTIARY SYSTEM—EOCENE SERIES.

Strata of Eocene age cap the Book Cliffs and for several thousand square miles constitute the surface of the Uinta Basin to the north. In the east end of the basin the Hayden Survey[a] mapped the Wasatch, Green River, Bridger, and Uinta formations of the Eocene, and in the west end G. H. Eldridge[b] also recognized the same formations. The present reconnaissance survey was not extended north of the crest of the Book Cliffs, and the large area designated Eocene on the map is taken from the authorities above mentioned.

The lower Eocene beds in the area here considered are composed of local conglomerate, varicolored shale, buff sandstone, and subordinate thin lenses of limestone. The stratigraphy is characteristically varied and many adjacent sections are very unlike; in one place the varicolored shale predominates and in another it is inconspicuous. The conglomerate also is variable in occurrence. In some sections none was seen, while elsewhere there is considerable. One of the best exposures observed is north of Thompsons, where from 10 to 20 feet

[a] Hayden's Atlas of Colorado.

[b] Eldridge, G. H., Asphalt and bituminous rock deposits of the United States: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 1, 1901.

of gray conglomerate rests upon an undulating surface of massive buff sandstone. The conglomerate is interbedded with lenses of fine red sandstone and is composed of rounded pebbles of quartz, quartzite, and chert, colored red, pink, black, and white, in a sandy matrix. Above the conglomerate north of Thompsons there are several beds of buff sandstone and drab shale and three thin intercalated layers of conglomerate, above which there are several hundred feet of red, purple, green and drab shales, including a few thin beds of drab siliceous limestone.

The following sections indicate general conditions, their upper limits marking no particular horizons.

Section of Eocene in Horse Canyon.

	Feet.
Shale, yellowish	4
Limestone, fine buff to white (rich in fossils, p 21)	1
Shale, drab	20
Sandstone, calcareous	1
Shale, varicolored	10
Sandstone, buff	5
Shale, green, purple, red	15
Shale, drab	20
Shale, varicolored	10
Shale, drab	25
Sandstone, buff	4
Shale, drab	10
Shale, varicolored	40
Shale, drab	20
Shale, varicolored	40
Shale, drab	20
Sandstone, white	10
Shale, drab	10
Sandstone, greenish	1
Shale, olive-drab, sandy	45
Shale, buff to drab, sandy	25
Conglomerate and sandstone	4
Sandstone, massive, buff (Mesaverde?).	
	340

Section of Eocene 5 miles north of Turner's ranch.

	Feet.
Sandstone, buff and white	20
Shale, red	7
Shale, purple	2
Sandstone, buff	2
Shale, purple	3
Shale, drab	12
Shale, red	7
Shale, drab	37
Sandstone, buff	15
Concealed by talus	115
Sandstone, buff	25
Shale, drab	15
Sandstone, gray	7
Shale, purple	7
Shale, drab	35
Sandstone, buff	15
Shale, reddish	18
Sandstone, buff	2
Shale, drab	25
Sandstone, buff	5
Shale, drab	25
Shale, purple	5
Sandstone, buff	5
Shale, drab	20
Shale, red and purple	75
Sandstone, massive, white (Mesaverde?).	
	504

At least 750 feet of the variegated beds are exposed in this area, but the top of the formation was not determined. Peale[a] gives the following measurements of the Eocene at White Mountain on Grand River north of De Beque: Green River, 2,282 feet; Wasatch, 1,650 feet; total Eocene, 3,932 feet.

[a] Peale, A. C., Geological report on the Grand River district: Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, p. 190.

Fossils are not abundant in the lower part of the Eocene series in the area under consideration, and collections were made in only two localities, each from thin beds or lenses of limestone. The following determinations were made by W. H. Dall:

Fossils collected near divide of Hay Creek, north of Turner's ranch, about 200 feet above top of Mesaverde.

Goniobasis tenera Hall var. carteri Conrad.
Cast of Polygyra (aff. leidyi Hall).
Impression of Unio sp.

Fossils from Horse Canyon, Utah, 200 and 350 feet above top of Mesaverde.

Physa, probably bridgerensis Meek.
Vivipara panguitchensis White.
Vivipara, probably wyomingensis Meek.
Goniobasis sp.

Dall reports that these are fresh-water shells which do not indicate with much precision their horizon within the Eocene, though they are probably Wasatch. Probably part of the area colored as Eocene on the map includes other Eocene formations in addition to the Wasatch, but the region has not been studied in detail and their differentiation was not attempted.

The presence or absence of the Fort Union formation, which normally occurs beneath the Wasatch, has not been determined in the Book Cliffs field. In the Grand Hogback, northwest of Newcastle, Colo., T. W. Stanton and H. S. Gale collected fossil plants which F. H. Knowlton refers to the Fort Union, but Gale did not find it practicable to map the rocks containing these fossil leaves distinct from the Wasatch. In the Book Cliffs field no Fort Union fossils have been found and the age of the thin, variable zone of conglomerate and buff sandstone at the base of the Eocene remains to be determined.

STRUCTURE.

The strata of the Book Cliffs coal field, forming as they do part of the southern margin of the Uinta synclinal basin, dip gently northward. The dip is not uniform, however, for this area, besides being included in the zone of folding of the Uinta Mountains and the Uinta Basin, is affected by the uplifts which produced the San Rafael Swell and the Uncompahgre Plateau. That part of the Book Cliffs coal field which is included in the present report is gently warped, the eastern part constituting the end of a low, northward-plunging anticline, and the western part the end of a northward-plunging syncline. Conforming with this structure, the irregular S-shaped outline of the cliffs coincides with the strike of the rocks. There are, also, local faults of small displacement.

The rocks in the foothills at the northern end of the Uncompahgre Plateau, near Grand Junction and Mack, dip northeastward at angles varying from 5° to 45°. Near the mouth of Gunnison River the Dakota sandstone dips 5°; west of Fruita the dip is 40° N. 40° E., and east of Mack it is 30° N. 55° E. Several miles west of Mack the direction of the Dakota outcrop turns and trends southwestward and the sandstone dips northwestward at angles ranging from 2° to 15°.

Between the Uncompahgre Plateau and the San Rafael Swell the rocks are irregularly disturbed, but little is known of the structure. South of the railroad between Cisco and Thompsons the Dakota outcrop trends almost east-west and dips northward. Seven or eight miles southwest of Thompsons the trend turns abruptly southward, forming the nose of a northwestward-pitching anticline. The axis of this fold is eroded and the vari-colored shales of the Jurassic are exposed between ridges of Dakota sandstone which on the north dips 10° N. 25° E. South of the town of Green River the dip of the Dakota indicates the presence of another low northward-pitching anticline, the dips varying from 5° to 15°.

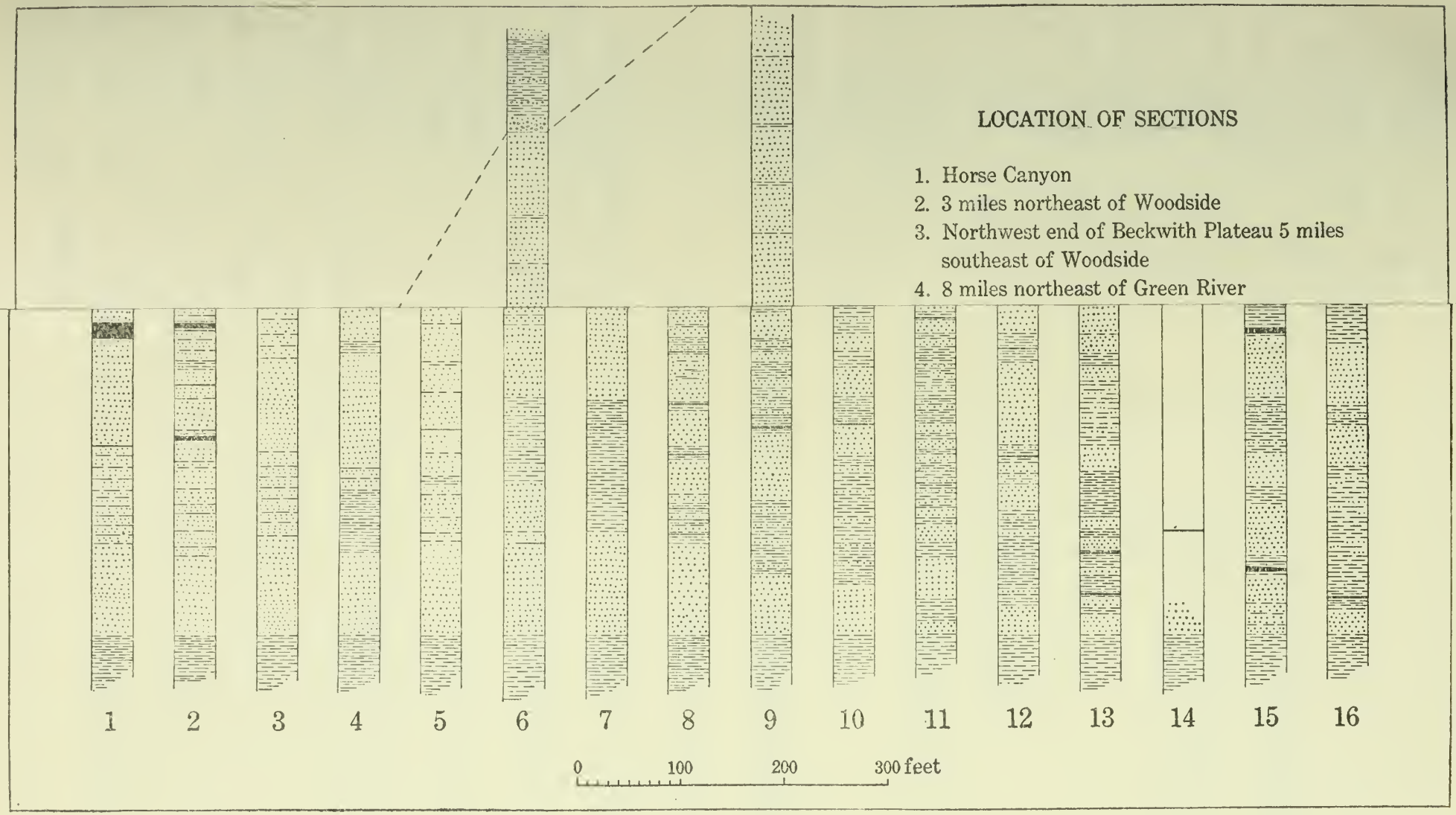
West of Green River the San Rafael uplift causes the highland to be fringed by prominent hogbacks formed by steeply dipping strata. The Dakota outcrop constitutes the outermost belt of foothills, in which the sandstone west of the town of Green River dips almost due east and in the vicinity of Price River northeast, the angles averaging about 10°.

The Mancos shale underlying the valley between the Dakota hills and the Book Cliffs doubtless conforms to the general structure of this region, but there are few opportunities for measuring the dips. Locally, however, especially where interbedded limestone and sandstone outcrop, the dip is shown to be low, and throughout the valley it probably ranges between 1° and 5°.

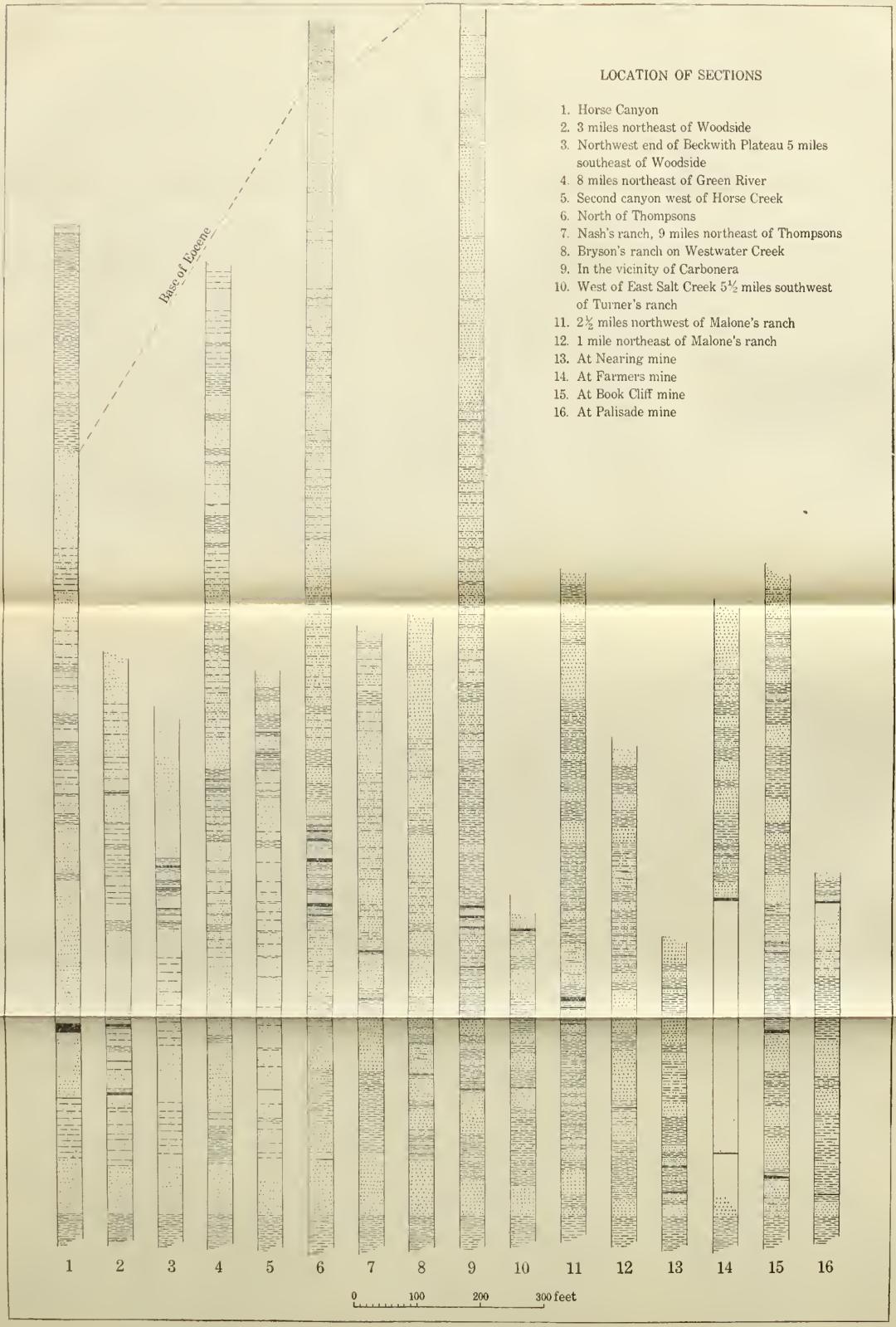
On the other hand, the structure of the rocks that form the cliffs is well exposed. Between Palisades and Carbonera the general dip is northeastward, the usual angle being about 4°. But in the vicinity of the Book Cliff mine, north of Grand Junction, the dip is locally steep, amounting to 25° or 30° N. 50° E. This dip continues down the northeastern side of the Little Book Cliffs, forming a dip slope; the steep inclination soon changes, however, to the prevailing low dip.

Two miles north of Carbonera a local fold is exposed which causes a southwestward dip of 15°, but the extent of this disturbance was not determined. It is south of the zone of doming found by H. S. Gale[a] in the White River valley in 1907. From Carbonera to the vicinity of Thompsons the dip in the face of the cliffs is about 5° NW., but, as is general throughout the field, it becomes less toward the

[a] Gale, H. S., Coal fields of northwestern Colorado and Utah: Bull. U. S. Geol. Survey No. 341 1909.



DETAILED COLUMNAR SECTIONS OF COAL-BEARING ROCKS IN BOOK CLIFFS FIELD.


LOCATION OF SECTIONS
1. Horse Canyon
2. 3 miles northeast of Woodside
3. Northwest end of Beckwith Plateau 5 miles southeast of Woodside
4. 8 miles northeast of Green River
5. Second canyon west of Horse Creek
6. North of Thompsons
7. Nash's ranch, 9 miles northeast of Thompsons
8. Bryson's ranch on Westwater Creek
9. In the vicinity of Carbonera
10. West of East Salt Creek 5½ miles southwest of Turner's ranch
11. 2½ miles northwest of Malone's ranch
12. 1 mile northeast of Malone's ranch
13. At Nearing mine
14. At Farmers mine
15. At Book Cliff mine
16. At Palisade mine
Base of Eocene
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
0 100 200 300 feet

DETAILED COLUMNAR SECTIONS OF COAL-BEARING ROCKS IN BOOK CLIFFS FIELD.

plateau. Northwest of Thompsons, to the end of the area examined, the influence of the San Rafael Swell is felt and the dips are northeastward from 2° to 10°.

The rocks in the Book Cliffs are conspicuously jointed, two sets at right angles being well developed, one of which usually is parallel to the face of the cliffs. The escarpment is gradually being worn back by blocks of sandstone breaking along these cracks and falling down to the base of the cliffs.

Large faults have not been observed in the Book Cliffs coal field, but several small dislocations were found in the face of the escarpment, a few of which will be mentioned. Between Sunnyside and Woodside the coal in the face of the cliffs is so distinctly offset that a fault can be seen at a distance of several miles, and there are several other faults in this vicinity. About 10 miles north of Woodside the plane of one fault strikes N. 65° W. and the displacement amounts to 120 feet. Another fault in the cliffs 3 miles northeast of Woodside strikes N. 75° W. Here the displacement is only about 20 feet, but the fault is clearly exposed, for it involves a bed of coal and the strata are bent along the plane of dislocation. There is also a small development of breccia. Another fault is clearly exposed in the canyon 2½ miles below Carbonera. (See Pl. II, *B*.) There the fault strikes N. 75° E. and the throw amounts to about 50 feet.

COAL.

GENERAL STATEMENT.

Coal of commercial importance occurs in the lower part of the Mesaverde formation at various horizons from 35 to 700 feet above its base. In some localities several beds are present, while in others only one or two have been found, but no single bed has been traced continuously for more than a few miles. (See Pl. VI.) So little prospecting has been done that an unqualified statement can not be made, but so far as known one or more workable beds are present throughout the field here considered. The thickness of the coal ranges from a maximum of 21 feet down to mere films of carbonaceous matter. The beds outcrop in the face of the Book Cliffs commonly 100 feet or more above their bases, and at distances from the Denver and Rio Grande Railroad which vary from close proximity to a maximum of about 15 miles. The dip is at a low angle northward and the coal underlies an immense area north of the cliffs. The coal is of good quality and compares favorably with that from the Rocky Mountain fields. It is but little prospected, however, and there are only four small mines with railroad connections between Grand River and Sunnyside.

OCCURRENCE AND THICKNESS.

The following description begins at the east and proceeds westward. In connection with it the map (Pl. I), the stratigraphic section (Pl. III), and the detailed coal measurements shown on Plate VIII will be of service.

At the east end of the Book Cliffs two workable beds of coal are known. The lower one occurs between 35 and 60 feet above the top of the Mancos shale, and, though variable, is commonly about 4 feet thick. The upper coal is thicker, in places measuring 9 feet, and occurs from 200 to 500 feet above the lower bed. These coal beds have been prospected at several localities between the Cameo mine (No 1 on the map, Pl. I) and the Farmers mine (No. 13), and, though they have not been actually traced throughout that distance and are known to vary in thickness, the beds appear to be continuous. Besides these two main coals there are usually other thin beds, but none of commercial importance has yet been found.

The following detailed measurements made in the face of the cliffs a quarter of a mile west of the Book Cliff mine show the succession of the strata at that place and indicate the general stratigraphy of the coal measures, although no two sections are exactly alike:

Section of coal-bearing rocks one-fourth mile west of Book Cliff mine.

	Ft.	in.
Sandstone, massive buff	35	
Sandstone, buff	15	
Shale, drab and sandy	15	
Coal and bone	1	3
Shale, drab	17	
Shale, carbonaceous	12	
Sandstone, buff	12	
Shale, drab	1	4
Bone and coal	1	6
Shale, drab	1	4
Bone and coal	1	9
Clay		2
Bone and coal	1	9
Shale, drab	2	
Sandstone, buff	7	
Shale, sandy	1	4
Shale, carbonaceous		6
Shale, drab		9
Coal	1	6
Shale, drab	1	8
Sandstone, buff	2	
Shale, carbonaceous and bone	6	
Sandstone, buff	3	
Shale, carbonaceous	2	6
Sandstone, massive buff	6	6
Shale, carbonaceous	17	

LITTLE BOOK CLIFFS AND GRAND RIVER NORTHEAST OF PALISADES.

The Cameo coal outcrops on the lowest wooded bench and the Palisades coal appears 450 feet lower, immediately below the lowest heavy sandstone.

1
Horse Canyon
Tunnel on W. side

2
1½ miles south of
Horse Canyon
section

3
7 miles n
Wood

11
Uinta R.R. mine

22
Cameo coal
Prospect north of
Palisades

14
Lane

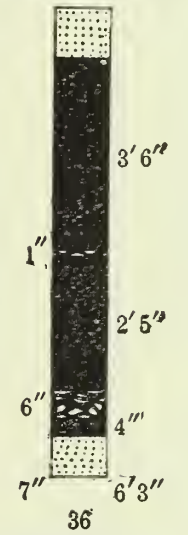
34
Palisade coal
Prospect 2 miles
of Book Cliff mine

12
3 miles SW. of
Turner's ranch

35
Palisade coal
Garfield mine

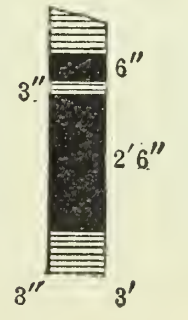
13
3 miles north of
Malone's ranch

23
Cameo coal
Prospect NE. of
Palisade mine

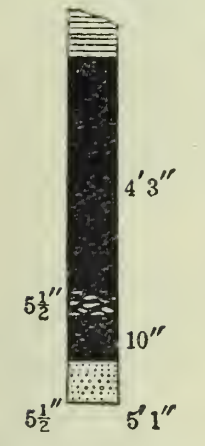


36
Palisade coal
Palisade mine

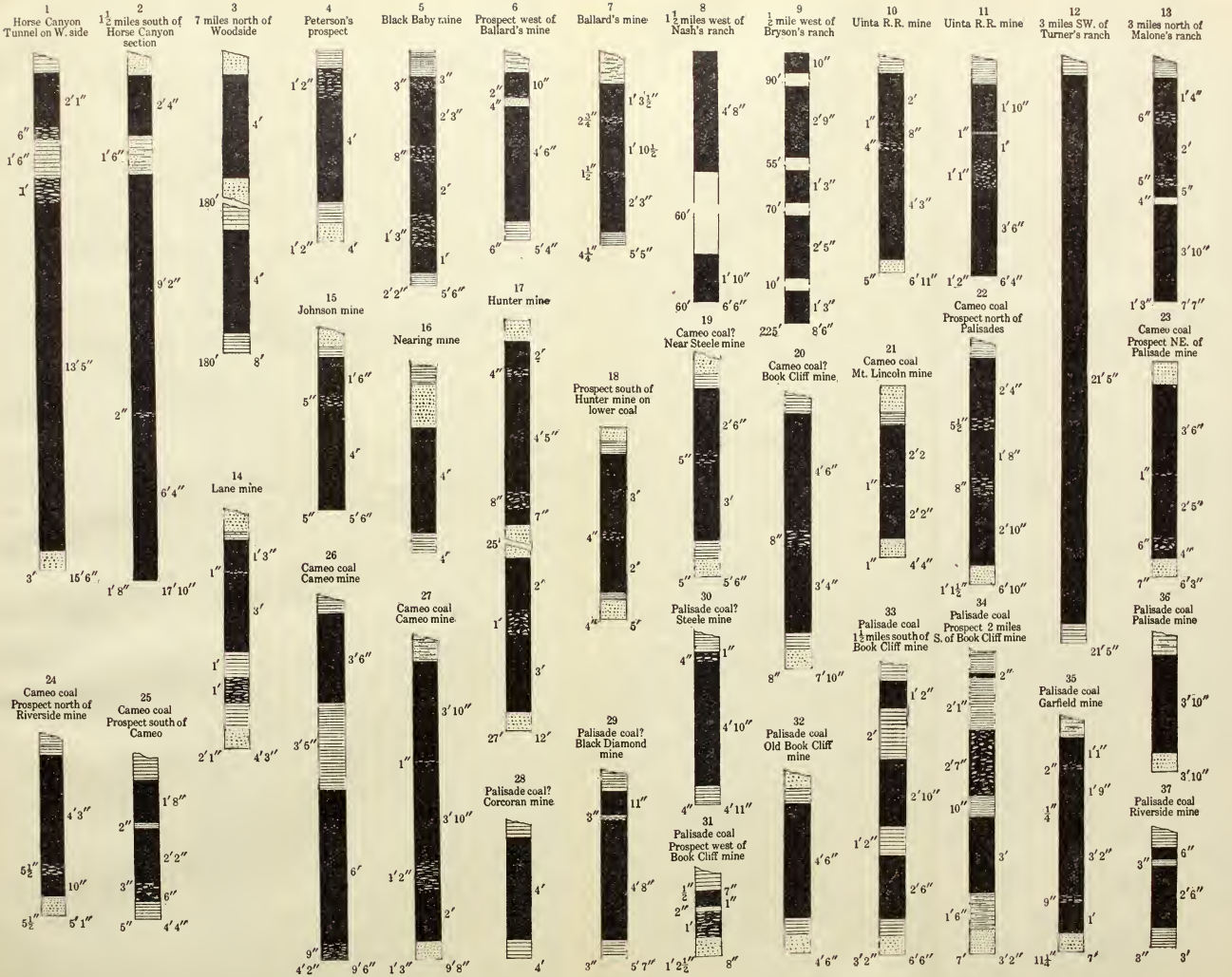
37
Palisade coal
Riverside mine



24
Cameo coal
Prospect north of
Riverside mine



25
Cameo coal
Prospect south of
Cameo


1 Horse Canyon Tunnel on W. side
2 1½ miles south of Horse Canyon section
3 7 miles north of Woodside
4 Peterson's prospect
5 Black Baby mine
6 Prospect west of Ballard's mine
7 Ballard's mine
8 1½ miles west of Nash's ranch
9 ½ mile west of Bryson's ranch
10 Uinta R.R. mine
11 Uinta R.R. mine
12 3 miles SW. of Turner's ranch
13 3 miles north of Malone's ranch
14 Lane mine
15 Johnson mine
16 Nearing mine
17 Hunter mine
18 Prospect south of Hunter mine on lower coal
19 Cameo coal? Near Steele mine
20 Cameo coal? Book Cliff mine
21 Cameo coal Mt. Lincoln mine
22 Cameo coal Prospect north of Palisades
23 Cameo coal Prospect NE. of Palisade mine
24 Cameo coal Prospect north of Riverside mine
25 Cameo coal Prospect south of Cameo
26 Cameo coal Cameo mine
27 Cameo coal Cameo mine
28 Palisade coal? Corcoran mine
29 Palisade coal? Black Diamond mine
30 Palisade coal? Steele mine
31 Palisade coal Prospect west of Book Cliff mine
32 Palisade coal Old Book Cliff mine
33 Palisade coal 1¼ miles south of Book Cliff mine
34 Palisade coal Prospect 2 miles S. of Book Cliff mine
35 Palisade coal Garfield mine
36 Palisade coal Palisade mine
37 Palisade coal Riverside mine

COAL SECTIONS IN BOOK CLIFFS COAL FIELD, COLORADO AND UTAH.

Section of coal-bearing rocks one-fourth mile west of Book Cliff mine—Continued.

	Ft.	in.
Sandstone, brown	1	4
Shale, sandy	1	6
Coal		5
Shale, drab	3	6
Sandstone, gray	3	6
Shale, carbonaceous	11	
Sandstone, buff	2	
Shale, carbonaceous	4	6
Sandstone, buff	1	
Shale, drab	1	
Shale, carbonaceous	1	4
Sandstone, drab	2	
Coal		1
Shale, drab	6	
Sandstone, drab	4	6
Shale, carbonaceous	4	
Coal "upper bed"	8	5
Shale, carbonaceous	1	6
Shale, drab, sandy	14	
Coal	2	6
Shale, carbonaceous	1	5
Coal	1	10
Bone		2
Coal		8
Sandstone, carbonaceous		4
Sandstone, massive, white	60	
Shale, drab	10	
Sandstone, buff	3	
Shale, drab	26	
Sandstone, brown	3	
Shale, drab	5	
Sandstone, massive, brown	37	
Shale, sandy	16	
Sandstone, buff	50	
Shale, drab	5	
Coal		6
Shale, carbonaceous		10
Coal "lower bed"	1	4
Shale, carbonaceous, sandy	1	
Sandstone, massive white	25	
Shale and sandstone, thin-bedded	30	
Shale, Mancos.		
	519	

The lower bed, known as the Palisades coal, outcrops at water level near the mouth of the Hogback Canyon of Grand River, about 1½ miles above Palisades (Pl. VII). Thence the coal bed rises rapidly above the valley and can be traced westward along the base of the Book Cliffs for several miles. At the Palisade mine (No. 6) the coal is about 150 feet above the valley, at the Garfield mine (No. 7) 800 feet, and at the old Book Cliff mine (No. 9) about 1,200 feet.

Throughout this distance the coal can be easily followed. At many places it is exposed by erosion, appearing as a black streak in the cliffs, and it is usually underlain by a massive white sandstone which is conspicuous as the first heavy sandstone bed above the Mancos shale. This sandstone is not persistent, however, but locally thickens and thins and gives way to shaly beds. The Palisades coal varies in thickness from a few inches to 6 feet. At the Riverside mine (No. 4), a mile northeast of Palisades, near the mouth of the entry, the following section is exposed:

Section of coal bed at Riverside mine.

	Ft.	in.
Shale.		
Coal		6
Shale		3
Coal	2	6
	3	3

At the face of the workings the shale parting is 1½ inches thick and the lower bench of coal is 2 feet 10 inches thick.

At the Palisade mine (No. 6) there is from 3 feet 7 inches to 3 feet 10 inches of clean coal.

Two miles west, at the Garfield mine, the Palisades coal attains the greatest thickness yet measured. The following section is there exposed:

Section of coal bed at Garfield mine.

	Ft.	in.
Sandstone, shaly.		
Coal	1	1
Bone		2
Coal	1	9
Bone		¼
Coal	3	2
Bone		9
Coal	1	
Total coal bed	7	11¼

About 2 miles south of the old Book Cliff mine (No. 9), in an abandoned prospect, the following section is exposed:

Section 2 miles south of old Book Cliff mine.

	Ft.	in.
Shale.		
Coal		2
Shale, carbonaceous	2	1
Coal and bone	2	7
Shale		10
Coal	3	
Shale, sandy	1	6
Sandstone.		
Total coal bed	5	9

In the vicinity of the old Book Cliff mine the lower coal is of variable thickness; in places it measures almost 5 feet, while near by it thins out to almost nothing, as shown by the following sections:

Section of coal bed at the old Book Cliff mine.

	Ft.	in.
Sandstone.		
Shale		7
Coal	4	6
Shale		8
Sandstone.		
	5	9

Section of coal bed 1 mile southeast of old Book Cliff mine.

	Ft.	in.
Shale.		
Coal	4	6
Shale		8
Coal	3	4
Shale		8
Sandstone.		
Total coal bed	8	6

Section of coal bed 1 mile southeast of the above section.

	Ft.	in.
Shale.		
Coal	1	
Shale		6
Coal	2	10
Shale	2	6
Coal	1	8
Shale		8
Sandstone.		
	9	2

It is reported that in working the lower coal in the old Book Cliff mine several areas were encountered in which the coal is absent. Northwest of the old mine evidences of thinning are shown by the following section:

Section of lower coal bed near Book Cliff mine.

	Ft.	in.
Shale, carbonaceous, interlaminated with thin coaly layers up to one-half inch	6	
Coal		2
Shale, carbonaceous and bony	4	
Bone		2
Coal and bone		9
Shale, carbonaceous		7
Coal	1	5
Shale, carbonaceous		7
Sandstone.		
	13	8

About a quarter of a mile west of this place the following section is exposed at the same horizon:

Section of lower coal bed near Book Cliff mine.

	Ft.	in.
Shale	6	
Coal		7
Bone		½
Coal		1
Sandstone		2
Shale, carbonaceous	1	
Sandstone.		
Total coal		8½

West of the Book Cliff mine less prospecting has been done than in the region to the east, but little variation in the thickness of the coal bed has been reported. At the Steele or Keystone mine (No. 11) there is 5 feet 3 inches of coal, including 4 inches of bone 1 foot from the top. The roof and floor are of shale, and the coal lies 3 feet above a bed of massive white sandstone.

At the Black Diamond mine (No. 12) the following section was measured:

Section of coal bed at Black Diamond mine.

	Ft.	in.
Shale.		
Coal		10
Clay		2
Coal	4	8
Shale.		
Total coal	5	6

Locally the coal bed is only 3 feet thick. At the Farmers mine the lower bed appears to be only 30 inches thick, but the upper coal is of greater value.

Except in two important mines, the Book Cliff (No. 10) and the Cameo (No. 1), the upper coal is not worked on a commercial scale in this locality, partly because the lower coal in general is of better quality, but chiefly because the lower coal is more accessible, occurring several hundred feet nearer the base ot the cliffs.

The upper bed, known as the Cameo coal, outcrops at river level at Cameo, on the Denver and Rio Grande Railroad. To the southwest it rises, and north of Palisades is 650 feet above the valley, lying at the base of the second tier of cliffs. (See Pl. VII.) From Palisades the outcrop extends northwestward to the vicinity of the Book Cliff mine, at a distance of about a mile and a half from the crest of the lower escarpment. Thence westward the bench below the upper coal disappears and the two coal beds outcrop in the face of the cliffs, almost directly one above the other. The position of the upper coal is marked by a massive white sandstone almost immediately beneath it. This sandstone is locally 75 feet thick and can be traced for miles, but it is not constant and locally disappears.

Between the Cameo and the Bob Cat mines the thickness of the upper coal, as exposed in mines and prospects, varies from 4 feet 4 inches to 9 feet 8 inches, with one or two partings of shale or bony coal ranging from 5 inches to 3 feet 5 inches in thickness.

In the Cameo mine the roof is a good, firm, sandy shale, and the floor, where the full thickness of coal is worked, is reported to be sandstone, but usually the total thickness of the coal is not removed. The coal has the reputation of being dirty, a condition which is due to the partings it contains. The following measurements were made in the mine at the localities indicated:

Sections of coal bed in the Cameo mine.

IN THE MAIN ENTRY.

	Ft.	in.
Coal	3	10
Bone		1
Coal	3	10
Bone	1	2
Coal	2	
	10	11

IN ROOM 5 OFF MAIN ENTRY.

	Ft.	in.
Coal	2	4
Bone		1
Coal	6	2
	8	7

AT END OF MAIN ENTRY.

	Ft.	in.
Coal	2	2
Bone		1
Coal	6	
	8	3

AT THE NORTHWEST END OF THE WORKINGS.

	Ft.	in.
Coal	2	
Bone		1
Coal	5	11
	8	

At a small prospect about a mile south of Cameo, on the west side of the river, the following section was measured:

Section of coal bed 1 mile south of Cameo.

	Ft.	in.
Coal	1	8
Bone		2
Coal	2	2
Bone		3
Coal		6
	4	9

A stripping was made of the Cameo coal west of the Grand River bridge above Palisades which showed the following sections:

Section of Cameo coal bed west of Grand River bridge.

	Ft.	in.
Coal	2	4
Bone		5½
Coal	1	10
Bone		8
Coal	2	8
	7	11½

At a prospect north of Palisades the following section is exposed:

Section of coal bed at prospect north of Palisades.

	Ft.	in.
Coal	3	6
Bone		1
Coal	2	5
	6	

At the Book Cliff mine (No. 10) about 7 feet of coal is worked, and at the end of the main entry the following section was measured:

Section of coal bed at end of main entry in Book Cliff mine.

	Ft.	in.
Coal	3	
Bone		¼
Coal	4	6
	7	6¼

At the face of the northwest entry 7 feet of coal is exposed, and 14 or 15 inches of bony coal is reported above and below this. In one of the main rooms the section is as follows:

Section of coal bed in room of Book Cliff mine.

	Ft.	in.
Coal	7	1
Bone		10
Coal		6
	8	5

About a quarter of a mile east of the Steele mine a stripping showed the following section:

Section of coal bed one-fourth mile east of Steele mine.

	Ft.	in.
Coal	2	6
Bone		5
Coal	3	2
Shale		8
Sandstone.		
Total coal bed	6	1

At the Bob Cat mine (No. 14) and in that vicinity between 44 and 55 inches of clean coal is exposed at the upper (?) coal horizon, which occurs about 400 feet above the lower bed worked at the Farmers mine. West of the Bob Cat mine the upper coal has not

been prospected and little is known of it for several miles. The coal outcrops high up in the face of the cliffs and the lower bed is more accessible.

There are two small openings on the lower coal west of the Farmers mine, which are known as the Excelsior and Corcoran mines. The Excelsior mine (No. 15) is located high up a hillside, near the head of a small gulch, where the coal is opened along the outcrop at several places. Here 4 feet 7 inches of coal is exposed at the entrance to the workings. Four feet above there is a 4-inch bed, and a foot and a half below there is 2 inches of coal, while 40 feet below the main coal there is an unprospected bed of coal and carbonaceous shale 6 feet thick. A mile west of the Excelsior mine there is a small abandoned prospect known as the Corcoran mine (No. 16). The workings have caved, but there is at least 4 feet of coal exposed near the entrance.

For 5 miles northwest of the Corcoran property little or no prospecting has been done, but at the next wide valley there are prospects on two beds of coal. An opening on the lower bed shows the following section:

Section of coal bed 5 miles northwest of Corcoran mine.

	Ft.	in.
Sandstone.		
Shale		6
Coal	3	
Bone		4
Coal	2	
Shale		4
Sandstone.		
Total coal bed	5	4

Farther up the same valley an upper coal is well exposed and has been worked at the Hunter mine (No. 17), where the following section was obtained:

Section of coal beds at Hunter mine.

	Ft.	in.
Sandstone.		
Coal	2	
Bone		4
Coal	4	5
Bone		8
Coal		7
Sandstone	25	
Coal	2	
Bone	1	
Coal	3	
Sandstone.		
	39	

The Gross or Kiel mine is situated 5 miles northwest of the Hunter property, near the mouth of Kiel Canyon. Between these mines no prospecting has been done and no information was obtained regarding the coal beds. At the Kiel mine (No. 18) from 3 feet to 3 feet 9 inches of coal is exposed at the approximate horizon of the lower bed.

The next opening is about a mile and half west of the Kiel, at the Nugent mine (No. 19). Here there are two openings on the lower (?) coal, on opposite sides of a gulch. The coal varies in thickness from 4 feet 3 inches to 4 feet 8 inches.

At the Nearing mine (No. 20), three-quarters of a mile west of the Nugent, the same bed is also worked. At the mouth of the mine the coal measures 4 feet to 4 feet 2 inches and contains a variable streak of bone up to 12 inches thick. At the end of the workings the bone disappears and the coal measures 4 feet 7 inches. The coal bed is here 45 feet above the top of the Mancos shale, and in this general vicinity the upper coal appears to be represented by only thin carbonaceous layers. Only one workable coal bed has been found in this locality. The following section was measured near this mine:

Section of coal-bearing rocks near Nearing mine.

	Ft.	in
Sandstone, buff	40	
Shale, drab	10	
Sandstone, red	10	
Shale, carbonaceous	1	6
Shale, buff	14	
Coal		8
Sandstone, buff	7	
Shale, buff	30	
Shale, carbonaceous	1	
Sandstone, white and buff	33	
Shale, carbonaceous		6
Sandstone, white	18	
Shale, carbonaceous	10	
Coal, bony		8
Sandstone, white	15	
Shale, sandy	60	
Sandstone, white	25	
Shale, buff	30	
Shale, carbonaceous	2	6
Shale, buff	10	
Coal		6
Sandstone, white	10	
Shale, buff	7	
Sandstone, buff	15	
Shale, carbonaceous		8
Coal	2	
Shale, carbonaceous	2	6
Shale, buff	10	
Sandstone, buff	7	
Shale, drab	15	
Sandstone, buff	1	8
Coal	4	
Shale, carbonaceous and drab	11	
Sandstone, buff	10	
Shale, drab	4	
Sandstone, buff	20	
Shale, Mancos.		
	439	2

Openings have been made on a coal bed at the Lane and Johnson mines, on opposite sides of a creek about 2 miles northwest of the Nearing property. At this place the following measurements were made:

Section of coal bed at the Johnson mine (No. 22).

Sandstone.	Ft.	in.
Shale, carbonaceous		5
Coal	1	6
Bone		3
Coal	4	
Total coal bed	5	9

Section of coal bed at the Lane mine (No. 23).

Sandstone.	Ft.	in.
Shale, sandy		4
Coal	1	3
Bone		4
Coal	3	
Shale, carbonaceous	1	
Coal, bony	1	
Total coal bed	6	7

A mile and a half up the creek there are several coal beds which have not been prospected, but which have the following section:

Section of coal beds 1½ miles east of Lane mine.

Shale.	Ft.	in.
Coal	1	4
Bone and coal		8
Coal	1	3
Shale, carbonaceous	2	
Coal	3	10
Shale, carbonaceous	18	
Coal		8
Shale, carbonaceous	7	
Coal	4	1
Shale.		
	38	10

The following section was measured at about the same horizon north of Malone's ranch:

Section of coal beds 3 miles north of Malone's ranch.

Shale, carbonaceous.	Ft.	in.
Coal	1	4
Bone		6
Coal	2	
Bone		5
Coal		5
Bone		4
Coal	3	10
Shale, sandy	7	
Coal	3	1
	18	11

The higher coal here is in two benches, as at the Hunter mine, but it has not been prospected. Little is known of the coal between the Lane and Johnson mines and Carbonera, near the Colorado-Utah boundary. Though undeveloped, coal has been found wherever sections have been made; for instance, at the west side of the entrance to the canyon of East Salt Creek, 6 miles southwest of Turner's ranch, there are two beds of coal, one 2 feet and the other 5½ feet thick, separated by an interval of about 252 feet.

Section at entrance of East Salt Creek canyon, 6 miles southwest of Turner's ranch.

	Ft.	in.
Sandstone, red	20+	
Coal	5	6
Shale, carbonaceous	21	
Sandstone, white, locally red	20	
Shale, drab	19	
Sandstone, buff	49	
Shale, drab, and thin beds of buff sandstone	54	
Sandstone, buff	19	
Shale, drab	15	
Sandstone, buff and white	30	
Shale, carbonaceous	25	
Coal	2	
Sandstone, buff and white	30	
Shale, drab, and thin beds of buff sandstone	125	
Sandstone, buff	50	
Shale, Mancos.		
	484	6

About 3 miles southwest of Turner's ranch and half a mile up from the mouth of a small eastern tributary of East Salt Creek a waterfall exposes a bed of coal 21 feet 5 inches thick, which is the thickest bed observed in the entire area under consideration. No development and but little prospecting have been done here, and the lateral extent of this coal bed has not been determined. It appears, however, to be a lens, for in following the coal to the west along the hillside above the gulch it was found to thin out and disappear.

Considerable prospecting has been done in the valley of West Salt Creek, and at Carbonera a mine is being worked by the Uinta Railway Company. In this vicinity the local undulating structure (see p. 22) causes the coal to lie within a relatively moderate depth below the surface. The following section was measured here:

Section of coal-bearing rocks near Carbonera.

	Ft.	in.
Sandstone, fossiliferous, buff (containing *Unio viripara*, *Goniobasis*, and *Tulotoma thompsoni*)	15	
Shale, drab, and thin beds of buff sandstone	65	
Sandstone, buff	4	
Shale, carbonaceous	3	
Sandstone, buff	5	

Section of coal-bearing rocks near Carbonera—Continued.

	Ft.	in.
Shale, drab	5	
Coal	3	4
Shale, carbonaceous	2	
Sandstone, buff	10	
Coal	3	10
Shale, carbonaceous	3	
Sandstone, buff	8	
Coal and bone	2	
Sandstone, thin bedded, buff, and shale	35	
Sandstone, buff	5	
Sandstone, buff, thin bedded, and shale	20	
Coal	2	
Shale, carbonaceous	2	
Shale, drab, sandy	10	
Sandstone, buff	5	
Shale, carbonaceous	15	
Sandstone, buff	2	
Shale, drab	3	
Sandstone, buff	7	
Shale, carbonaceous	18	
Sandstone, buff	7	
Shale, drab	3	
Sandstone, buff	10	
Shale, carbonaceous	2	
Sandstone, buff	25	
Shale, carbonaceous	3	
Sandstone, shaly	5	
Shale, carbonaceous	5	
Sandstone, buff	10	
Shale, drab	15	
Sandstone, shaly	10	
Coal		6
Shale, carbonaceous	2	
Sandstone, shaly	20	
Shale, carbonaceous	3	
Coal		10
Shale, carbonaceous	1	
Coal		10
Shale, carbonaceous	1	
Sandstone, buff, shaly	2	
Shale, carbonaceous	4	
Coal	2	
Shale, carbonaceous	5	
Sandstone, buff	65	
Shale, drab, including several thin beds of buff sandstone	70	
Sandstone, massive, buff	60	
Shale, Mancos.		
	585	4

Within a distance of less than 500 feet above the top of the Mancos shale there are five beds of coal, each 2 feet or more thick, and several other thinner carbonaceous layers. At the Carbonera mine the coal bed measures more than 7 feet, but it is parted by two layers of bone,

which greatly decreases the value. The following sections, measured in different parts of the mine, show the general condition of the coal bed:

Sections of coal bed in Carbonera mine.

	End of back entry.	Room No. 3.	Near entrance.
	Ft. in.	*Ft. in.*	*Ft. in.*
Coal	2 1	1 10	2
Bone	1	1	1
Coal	10½	1	8
Bone	5	1 1	4
Coal	4	3 6	4 3
	7 5½	7 6	7 4

In Utah within the area covered by this report there are no shipping mines and the coal has been prospected in only a few places. The coal lands have not been surveyed by the General Land Office, and the region is even more thinly populated than Colorado; between Carbonera, Colo., and Thompsons, Utah, a distance of more than 50 miles, there are only three ranches, which are situated near the mouths of canyons at the base of the Book Cliffs, where feeble streams flow throughout the year. In Utah, as in Colorado, the Mesaverde formation constitutes the cliff-making rocks, and coal has been found at the usual horizon wherever sections have been studied. Near Bryson's ranch, on Westwater Creek, the following measurements were made:

Section of coal-bearing rocks near Bryson's ranch, on Westwater Creek.

	Ft.	in.
Sandstone, thick bedded, buff	65	
Shale, carbonaceous	1	
Coal		1
Shale, drab	2	
Sandstone, thick bedded, buff	5	
Shale, carbonaceous	3	
Sandstone, thin bedded, buff	40	
Shale, carbonaceous	3	
Sandstone, thin bedded, buff	10	
Coal		10
Shale, carbonaceous	5	
Sandstone, thin bedded, buff	5	
Shale, carbonaceous	1	
Coal	1	10
Shale, carbonaceous	2	
Sandstone, thick bedded, buff	5	
Sandstone, shaly, buff	35	
Sandstone, thin bedded, buff	4	
Sandstone, thick bedded, buff	4	
Shale, carbonaceous	3	
Coal	2	9
Shale, carbonaceous	4	
Sandstone, thin bedded, buff	20	

Section of coal-bearing rocks near Bryson's ranch, on Westwater Creek—Continued.

	Ft.	in.
Sandstone, thick bedded, buff	13	
Sandstone, thin bedded, buff	3	
Shale, carbonaceous	7	
Coal	1	3
Shale, carbonaceous	4	
Sandstone, thick bedded, buff	3	
Sandstone, thin bedded, buff	15	
Sandstone, thick bedded, buff	10	
Sandstone, thin bedded, buff	15	
Shale, carbonaceous	5	
Coal	2	10
Shale, carbonaceous	3	
Sandstone, thin bedded	4	
Coal	2	5
Shale, carbonaceous	3	
Sandstone, thin bedded, buff	3	
Shale, carbonaceous	4	
Coal	1	3
Shale, carbonaceous	5	
Sandstone, thin bedded, buff, and shale	90	
Shale, Mancos.		
	417	3

Six beds of coal, ranging from 1 foot 3 inches to 2 feet 10 inches, were found in a zone 275 feet thick, the lowest coal occurring 95 feet above the top of the Mancos shale. From the Utah-Colorado boundary to some miles west of Thompsons a bench about 100 feet in height and half a mile to a mile in width, caused by a thick lens of sandstone in the shale, extends along the base of the cliffs, and the coal outcrop therefore lies farther back in the cliffs than usual.

Near Harms's ranch (No. 28), at the mouth of Cottonwood Canyon, there is a bed of coal 1 foot 6 inches thick. Mr. Harms reports beds varying in thickness from 2 inches to 3 feet, but says that the coal contains much bone and is of poor quality.

About a mile and a half above Nash's ranch (No. 29), in a canyon, two beds of coal were observed, separated by an interval of about 60 feet. The lower bed is 1 foot 10 inches thick and occurs 350 feet above the top of the Mancos shale; the higher bed measures 4 feet 8 inches, but little attempt has been made to develop it.

More work has been done on the coal north of Thompsons than anywhere else in Utah in the area covered by this report, although the prospecting even in this locality has not been thorough. Several beds of coal are present. The following section shows five beds more than $2\frac{1}{2}$ feet thick within 125 feet of strata:

Section of coal-bearing rocks north of Thompsons.

	Ft.	in.
Sandstone, massive, buff	25	
Coal		1
Shale, carbonaceous	6	
Sandstone, thin bedded	6	

Section of coal-bearing rocks north of Thompsons—Continued.

	Ft.	in.
Shale, carbonaceous	2	
Coal	1	6
Shale, carbonaceous	5	
Coal	2	6
Shale, carbonaceous	5	
Coal		5
Shale, carbonaceous	3	
Coal	4	
Shale, carbonaceous	2	
Sandstone, buff, shaly	10	
Sandstone, thick bedded, buff	15	
Coal	5	6
Shale, carbonaceous	15	
Sandstone, thin bedded	5	
Shale, carbonaceous	4	
Coal		2
Shale, carbonaceous	18	
Coal	2	6
Shale, carbonaceous	5	
Sandstone, thin bedded, buff	15	
Coal	6	
Shale, carbonaceous	3	
Coal	1	6
Shale, carbonaceous	9	
Coal	3	6
Shale, carbonaceous	10	
Sandstone, thin bedded, buff	40	
Sandstone, thick bedded, interbedded with shale	20	
Sandstone, thin bedded, buff	25	
Sandstone, thick bedded, buff	30	
Sandstone, thin bedded, buff	50	
Sandstone, massive, buff	70	
Shale, drab, interbedded with subordinate, thin, buff sandstone layers	95	
Sandstone, massive, fine textured, with local lenses of coal up to 1 foot 3 inches thick	150	
Shale, Mancos.		
	670	8

The principal work here has been done at the Ballard mine (No. 29), at which the following section was measured (see Pl. IX):

Section of coal bed at Ballard mine, near Thompsons, Utah.

Sandstone, shaly.	Ft.	in.
Coal	1	3
Bone		2
Coal	1	10½
Bone		1½
Coal	2	3
Shale, carbonaceous.		
	5	8

At the end of the workings there is 5 feet 10½ inches of coal with no partings.

substance derived from the leaching of the adjacent rocks. A test by George Steiger of some of this material from the coal in Horse Canyon, Utah, showed it to be a hydrous silicate of aluminum containing a small amount of calcium carbonate.

The moisture content of the coal is shown in the table of analyses on pages 44–46. The moisture in the "sample as received," which represents the condition of the coal in the mine, ranges from 4.71 to 18.63 per cent. By air drying in the laboratory these samples lost between 0.10 and 5.30 per cent of their moisture. On exposure to the weather the coal becomes dull and breaks up along the joints into small prisms which finally crumble to powder. The rapidity with which disintegration occurs is not well known, for little coal is allowed to remain about the mines. A considerable amount, however, was found at the prospects in Horse Canyon; although this was reported to have lain in a heap exposed to the weather for more than a year, it showed little apparent deterioration.

CHEMICAL COMPOSITION.

The following analyses show the composition of a number of samples of coal from the eastern part of the Book Cliffs field. Samples were taken from the most important mines and prospects under uniform conditions, and represent the freshest available material. The samples were collected by cutting a channel across the face of the coal from roof to floor, partings more than a quarter of an inch in thickness being rejected. The material was gathered on canvas, crushed, mixed, and quartered down to about 3 pounds, and sent to the laboratory in sealed cans. The analyses were made at the fuel-testing plant of the United States Geological Survey at St. Louis, under uniform conditions prescribed by N. W. Lord.[a]

The analysis of each sample is tabulated in two forms, showing the composition of the air-dried sample and the sample as received at the laboratory. The air-dried analysis shows the percentage of the several constituents of the coal after it has been powdered and allowed to lose the moisture that evaporates on exposure to the atmosphere of the laboratory until a constant weight results, the percentage of air-drying loss being shown in the table. The analysis of the sample as received shows the percentage of the several constituents of the coal, including the total amount of water contained in the sample as received at the laboratory, and represents the condition of the coal in the mine. For general purposes the figures for the air-dried sample are best for comparison with other analyses. Proximate analyses of

[a] Prof. Paper U. S. Geol. Survey No. 48, 1906, p. 174 et seq.

35 samples and ultimate analyses of 13 of the most nearly representative ones are given in the following tables:

Proximate analyses of coal samples from the Book Cliffs coal field.

[F. M. Stanton, chemist in charge.]

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Laboratory No.	3550.	3547.	3542.	3540.	3546.	3541.	3549.	3539.	3545.
Sample as received:									
Moisture	8.42	8.17	7.55	4.71	7.57	7.52	8.77	9.02	13.96
Volatile matter	33.32	33.69	31.07	34.68	33.56	36.03	36.55	34.51	31.30
Fixed carbon	47.53	53 42	48.27	52.66	52.91	50.46	48.72	50.89	48.73
Ash	10.73	4.72	13.11	7.95	5.96	5.99	5.96	5.58	6.01
Sulphur	.60	.57	.57	.56	.72	.85	.83	.67	.63
Loss of moisture on air drying	4.30	2.80	2.60	.10	2.20	2.00	2.50	3.10	4.40
Air-dried sample:									
Moisture	4.30	5.52	5.08	4.61	5.49	5.63	6.43	6.11	10.00
Volatile matter	34.82	34.66	31.90	34.72	34.32	36.77	37.49	35.61	32.74
Fixed carbon	49.67	54.96	49.56	52.71	54.10	51 49	49.97	52.52	50.98
Ash	11.21	4.86	13 46	7.96	6.09	6.11	6.11	5.76	6.28
Sulphur	63	.59	59	.56	.74	87	.85	.69	.66

	10.	11.	12.	13.	14.	15.	16.	17.	18.
Laboratory No.	3490.	3496.	3494.	3581.	3495.	3493.	3489.	3488.	3640.
Sample as received:									
Moisture	11 42	10.75	10.89	11.03	9.54	15.39	6.86	6.52	5.40
Volatile matter	34.25	34.83	34.12	35.90	34.49	32.57	34.20	35.75	33.30
Fixed carbon	44.49	47 58	44 77	46.35	46.33	45.69	43.90	48.37	55.57
Ash	9.84	6.84	10.22	6.72	9.64	6.35	15.04	9.36	5.73
Sulphur	.84	.55	1.09	.68	.78	.62	.62	.67	.49
Loss of moisture on air drying	5.60	3.50	5.20	5.80	3.10	7.20	1.80	.60	20
Air-dried sample:									
Moisture	6.17	7.51	6.00	5.55	6.65	8.83	5.15	5.96	5.21
Volatile matter	36.28	36.09	35.99	38.11	35.59	35.10	34.83	35.96	33.36
Fixed carbon	47.13	49.31	47.23	49.21	47.81	49.23	44.70	48.66	55.69
Ash	10.42	7.09	10.78	7.13	9.95	6.84	15.32	9.42	5.74
Sulphur	.89	57	1.15	.72	.80	.67	.63	.67	.49

	19.	20.	21.	22.	23.	24.	25.	26.	27.
Laboratory No.	3587.	3585.	3586.	3584.	3730.	3728.	3729.	3732.	3734.
Sample as received:									
Moisture	9.44	9.73	8.27	5.55	18.63	9.32	10.96	10.77	11.23
Volatile matter	35.51	35.27	36.90	36.01	30.61	33.64	32.19	33.68	31.51
Fixed carbon	49.33	49.95	48.67	52.75	46.28	49.52	42.45	48.36	45.31
Ash	5.72	5.05	6.16	5.69	4.48	7.52	14.40	7.19	11.95
Sulphur	1.02	1.30	1.26	.93	.38	.51	.48	.56	.42
Loss of moisture on air drying	5.50	5.20	3.60	1.60	9 10	3.00	4.50	3.90	4 70
Air-dried sample:									
Moisture	4.17	4.78	4.84	4.01	10.48	6.52	6.76	7.15	6.85
Volatile matter	37.58	37.20	38.28	36 60	33.68	34.68	33.71	35.05	33 07
Fixed carbon	52.20	52.69	50.49	53.61	50 91	51.05	44.45	50.32	47.54
Ash	6.05	5.33	6.39	5.78	4.93	7.75	15.08	7 48	12.54
Sulphur	1.08	1.37	1.31	95	.42	.53	50	58	.44

Proximate analyses of coal samples from the Book Cliffs coal field—Continued.

	28.	29.	30.	31.	32.	33.	34.	35.
Laboratory No.	3854.	3856.	3857.	3945.	3957.	4014.	4013.	4015.
Sample as received:								
Moisture	12.74	6.35	9.57	5.58	4.75	9.79	9.01	5.20
Volatile matter	33.04	31.89	32.37	32.77	33.58	33.39	31.78	36.03
Fixed carbon	50.06	42.74	47.09	43.61	50.24	50.44	51.03	52.69
Ash	4.16	19.02	10.97	18.04	11.43	6.38	8.18	6.08
Sulphur	.46	.58	.46	.72	1.15	.60	.46	.83
Loss of moisture on air drying	4.50	2.30	2.50	1.90	2.30	3.50	4.10	2.90
Air-dried sample:								
Moisture	8.63	4.14	7.25	3.75	2.51	6.52	5.12	2.37
Volatile matter	34.60	32.64	33.20	33.41	34.37	34.60	33.14	37.11
Fixed carbon	52.42	43.75	48.30	44.45	51.42	52.27	53.21	54.27
Ash	4.35	19.47	11.25	18.39	11.70	6.61	8.53	6.25
Sulphur	.48	.60	.47	.74	1.18	.62	.47	.85

Ultimate analyses of coal samples from the Book Cliffs coal field.

[F. M. Stanton, chemist in charge.]

	1.	5.	6.	7.	10.	18.	19.
Laboratory No.	2550.	3546.	3541.	3545.	3490.	3640.	3587.
Sample as received:							
Ash	10.73	5.96	5.99	6.01	9.84	5.73	5.72
Sulphur	.60	.72	.85	.63	.84	.49	1.02
Hydrogen	5.45	5.50	5.26	5.82	5.46	5.39	5.94
Carbon	65.52	69.47	68.43	62.19	61.84	70.18	68.47
Nitrogen	1.20	1.56	1.55	1.40	1.07	1.20	1.56
Oxygen	16.50	16.79	17.92	23.95	20.95	17.01	17.29
Calories	6,466	6,913	6,838	6,034	6,166	6,894	6,811
British thermal units	11,639	12,443	12,308	10,861	11,099	12,409	12,260
Carbon-hydrogen ratio	13.00	13.20	13.59	11.66	12.77	13.07	12.85
Loss of moisture on air drying	4.30	2.20	2.00	4.40	5.60	20	5.50
Air-dried sample:							
Ash	11.21	6.09	6.11	6.28	10.42	5.74	6.05
Sulphur	.63	.74	.87	66	89	.49	1.08
Hydrogen	5.19	5.38	5.14	5.58	5.13	5.38	5.64
Carbon	68.46	71.03	69.83	65.05	65.51	70.32	72.46
Nitrogen	1.26	1.60	1.58	1.47	1.13	1.20	1.65
Oxygen	13.25	15.16	16.47	20.96	16.92	16.87	13.12
Calories	6,757	7,069	6,978	6,312	6,532	6,908	7,207
British thermal units	12,162	12,723	12,559	11,361	11,757	12,434	12,973

Ultimate analyses of coal samples from the Book Cliffs coal field—Continued.

	20.	21.	25.	29.	34.	35.
Laboratory No	3585.	3586.	3729.	3856.	4013.	4015.
Sample as received:						
Ash	5.05	6.16	14.40	19.02	8.18	6.08
Sulphur	1.30	1.26	.48	.58	.46	.83
Hydrogen	5.81	5.54	5.63	5.01	4.97	5.26
Carbon	68.84	67.48	58.42	59.10	62.22	71.22
Nitrogen	1.55	1.57	1.24	1.32	1.25	1.29
Oxygen	17.45	17.99	19.83	14.97	22.92	15.32
Calories	6,809	6,771	5,815	5,890	6,035	7,239
British thermal units	12,256	12,188	10,467	10,602	10,863	13,030
Carbon-hydrogen ratio	13.16	13.13	11.59	12.45	13.77	14.41
Loss of moisture on air drying	5.20	3.60	4.50	2.30	4.10	2.90
Air-dried sample:						
Ash	5.33	6.39	15.08	19.47	8.53	6.25
Sulphur	1.37	1.31	.50	.60	.47	.85
Hydrogen	5.52	5.33	5.37	4.86	4.71	5.09
Carbon	72.62	70.00	61.17	60.49	64.88	73.35
Nitrogen	1.63	1.63	1.30	1.35	1.30	1.34
Oxygen	13.53	15.34	16.58	13.23	20.11	13.12
Calories	7,182	7,024	6,089	6,029	6,293	7,455
British thermal units	12,928	12,643	10,960	10,852	11,327	13,419

1–3. Sec. 34, T. 10 S., R. 98 W.
4. Upper coal, sec. 3, T. 11 S., R. 98 W.
5–8. Lower coal, sec. 3, T. 11 S., R. 98 W.
9. Sec. 6, T. 11 S., R. 98 W.
10–12. Upper coal, sec. 8, T. 10 S., R. 99 W.
13. First coal below upper coal, sec. 8, T. 10 S., R. 99 W.
14. Sec. 7, T. 10 S., R. 99 W.
15. Sec. 1, T. 10 S., R. 100 W. Weathered sample.
16. Sec. 36, T. 9 S., R. 100 W.
17. Sec. 35, T. 9 S., R. 100 W. Weathered sample.
18. Sec. 5, T. 9 S., R. 100 W.
19. Sec. 27, T. 8 S., R. 101 W.
20. Sec. 29, T. 8 S., R. 101 W.
21. Sec. 30, T. 8 S., R. 101 W.
22. Sec. 18, T. 8 S., R. 101 W.
23. Sec. 16, T. 7 S., R. 102 W. Weathered sample.
24. Sec. 11, T. 7 S., R. 104 W.
25–27. Sec. 14, T. 7 S., R. 104 W.
28. 1½ miles northwest of Nash's ranch, Utah.
29. 5 miles north of Thompsons, Utah.
30. 5 miles north of Thompsons, Utah.
31. 6 miles northeast of Solitude, Utah.
32. 4 miles east of Woodside, Utah.
33–34. 8 miles south of Sunnyside, Utah.
35. West side of Horse Canyon, 6 miles south of Sunnyside, Utah.

Inspection of the table of proximate analyses of air-dried coals shows the following range in percentages: Moisture, from 2.37 to 10.48; volatile matter, from 31.90 to 38.28; fixed carbon, from 43.75 to 55.69; ash, from 4.86 to 19.47. The table of ultimate analyses of air-dried coals shows the following range: Hydrogen, from 4.71 to 5.64; carbon, from 60.49 to 73.35; nitrogen, from 1.13 to 1.65; oxygen, from 13.12 to 20.96; sulphur, from 0.47 to 1.37. The calorific values, determined with a Mahler bomb calorimeter, range from 10,852 to 13,419 British thermal units.

Bearing in mind that the range shown by the analyses is partly due to different stages of weathering of the samples collected, although care was taken to obtain as fresh coal as possible, the analyses indicate that the coals from the different parts of the area examined are not strikingly different. The marked variations in quality of near-by coals, not uncommon in Rocky Mountain fields, especially in Colorado, are not found in the area here considered. Igneous rocks are not known to occur in the Book Cliffs, and the coals are not locally metamorphosed. There are many minor differences, however. In the eastern part of the field, for instance, a comparison of analyses of mine samples of coal from the upper and lower beds shows that the

upper bed contains more moisture and ash and less carbon than the lower coal, and that the lower coal has a greater efficiency as expressed by the calorific values. Judged by the analyses, the sample of coal showing the best results is the one from Horse Canyon, Utah, which, with 6.25 per cent of ash, gave an efficiency of 13,419 British thermal units, while the best results obtained in the eastern end of the field were from the lower coal near the mouth of the Hogback Canyon of Grand River, which, with 6.09 per cent of ash, showed an efficiency of 12,723 British thermal units.

An important difference is in the coking quality of these coals. The coal from Sunnyside, Utah, produces a coke of good grade, whereas thus far coals from the vicinity of Grand Junction yield such a low-grade product that they are classed as noncoking. Between these extreme locations, one at the eastern end of the area examined and the other beyond the western limit, no coking tests have been made; and it remains to be determined what coals, if any, in the eastern part of the Book Cliffs field will coke.

Comparison with analyses of other coals examined at the Government fuel-testing plant shows that the coals from the eastern part of the Book Cliffs field rank favorably with the product of other fields in the Rocky Mountain region and the Mississippi Valley. The Book Cliffs coals are classed as medium-grade bituminous.

MARKET AND USE.

The part of the Book Cliffs field under consideration is situated between areas where coal of similar quality and greater thickness is already being developed. The mines in the vicinity of Newcastle, to the east, and those about Castlegate, to the west, are more favorably situated for the large markets than is the eastern part of the Book Cliffs field. However, because of the proximity of the Denver and Rio Grande Railroad, it probably will not be long before this great reserve of coal will be more actively developed. Denver and Pueblo, Salt Lake City, and the Pacific coast are likely to be the most important outside markets, and there will be a growing local demand in connection with the increase of population and the development of Colorado and Utah mines. At present the local market is the only outlet.

There are only four mines with railroad connection in the field here discussed, and practically their entire product is used by the towns of Grand Junction, Palisades, and Fruita, and by the Uintah Railway. These mines are the Cameo (No. 1), Palisade (No. 6), Book Cliff (No. 10), and Carbonera (No. 25). At Grand Junction, besides a considerable amount of coal used for domestic purposes and for the gas and electric light plants, a sugar-beet factory and a smelter use coal from the Book Cliffs field. The other mines are worked

entirely for domestic purposes and the coal is transported by wagon. In 1906 the average cost of coal at the country mines was $1.75 a ton; at Palisades the price was quoted at $2.25 a ton, and at Grand Junction the retail price for lump coal not delivered was $3 a ton. Slack sold for between 50 and 75 cents a ton.

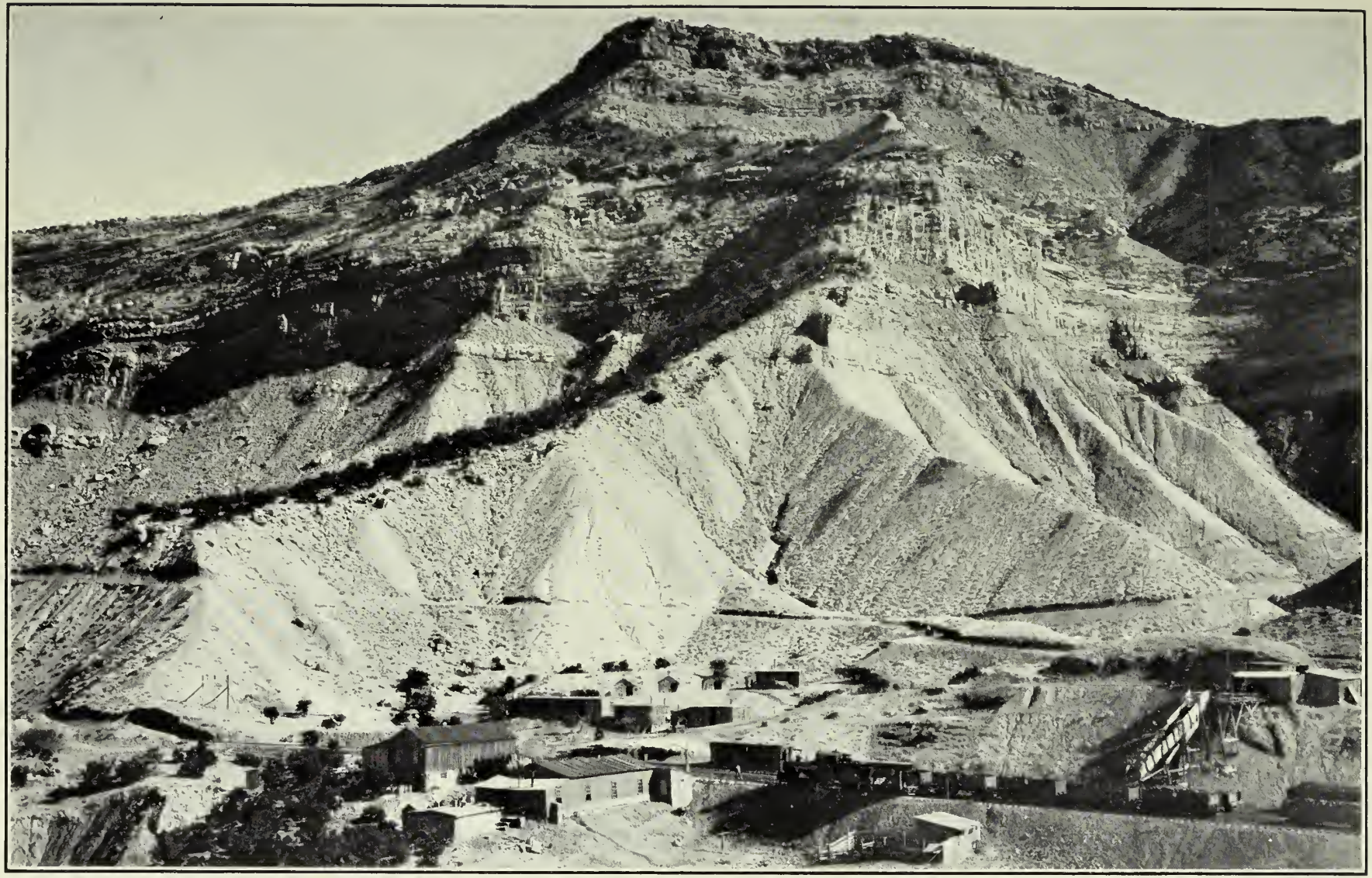
DEVELOPMENT.

Very little has been done in developing the eastern part of the Book Cliffs coal field. The four mines with railroad connections are reported to have produced in 1905 a total of only 5,300 tons, while the other mines are for the most part country banks that yield but a few hundred tons each a year.

The proximity of the field to a trunk railroad and the ease with which short branch lines can be constructed across the shale plain to the base of the cliffs render the transportation problem comparatively easy. The situation of the coal, however, several hundred feet above the base of the cliffs, except in the creek valleys, makes it difficult of access and usually necessitates the construction of a steep tramway or an aerial cable. Favorable conditions for reaching the coal by shafts are rare, except in the broader valleys, and the greater part of the coal probably will be worked from the outcrop.

An important consideration is the lack of water, which will prove a detriment to the commercial development of a large part of the field. Throughout the greater portion of the year there is either no surface water in the vicinity of the cliffs, away from Grand River, or water is present in very small quantity. Springs are scarce and the prospect of obtaining sufficient supplies of underground water is not favorable. The Cameo, Riverside, and Palisade mines, being near Grand River, do not experience this difficulty, and the Book Cliffs mine is located near one of the rare springs. Water is hauled from Atchee by the Uintah Railway for the men at the Carbonera mine. In the vicinity of several of the workings, as in Horse Creek, Utah, there is a small perennial stream, but for many miles along the cliffs there is insufficient water for mining purposes. Water from an irrigation canal is hauled by wagon to the mines north of Fruita, a distance of 8 or 10 miles.

The first development work on the coal in this area is said to have been in 1882 at the old Book Cliff mine, north of Grand Junction. The Cameo mine was opened about 1895, and the Palisade mine is reported to have been started also about that time. These are the chief mines of the area and they supply the needs of the settlements in Grand River valley. The Carbonera mine, the only other with railroad connections, was not opened until 1904, and is used entirely for the needs of the Uintah Railway, which is a short road from Mack, Colo., to the gilsonite deposits at Dragon, Utah. There are only



PROPERTY OF THE BOOK CLIFF MINE COMPANY AT THE BASE OF THE CLIFFS NORTH OF GRAND JUNCTION.

The "lower coal" occurs at the base of the lowermost massive sandstone and the "upper coal" 200 feet higher, immediately above the conspicuous bed of white sandstone. The view shows the transition from the Mancos shale to the overlying Mesaverde formation.

about thirty other small mines and prospects of any consequence within the area here reported; these are listed and their locations are shown on the map, Plate I.

The coal is opened at or near the outcrop and generally is worked by the room and pillar system. Where the dip is appreciable entries are run with the strike and the rooms are opened principally up the rise. The long-wall system is used at only one mine, the Riverside. Both roof and floor are generally a firm sandy shale. The workings usually are dry and little trouble is caused by water, but in a few instances, as at the Cameo mine, water level has been reached. Some of the workings are extremely dry and dusty and care must be taken to avoid explosion. Natural ventilation is chiefly depended on, though furnaces are used to some extent. Machines have not been introduced and in general the methods of mining are simple. The following brief descriptions will serve to indicate the present stage of development:

The Book Cliff mine, operated by the Book Cliff Coal Company, is situated in a small ravine in the Little Book Cliffs, about 12 miles north of Grand Junction. The mine is connected with the Denver and Rio Grande Railroad by a narrow-gage road, and the camp consists of a number of frame houses, a company store, workshop, etc. (See Pl. X.) Good water is supplied in moderate quantity from a near-by spring, which was an important factor in determining the location of the mine.

Considerable prospecting has been done in this vicinity. The lower bed was formerly worked; it has the advantage over the upper bed of being slightly better in quality and of outcropping about 190 feet lower down the cliffs. The old mine[a] is situated in the ravine next south of the one in which the present workings are located, and was approached by a steeply inclined tramway. The coal was reached by a tunnel cut through the underlying sandstone. Development proved, however, that the lower coal bed in this vicinity varies greatly in thickness, ranging from a few inches to about 4 feet, and after a few years work on the lower bed was abandoned. A considerable quantity of coal was mined, however, the largest production of any one year being reported as 18,000 tons.

In the present mine, which was opened in 1903, the upper coal is worked. It is reached through a tunnel, the mouth of which is situated near the lower coal outcrop, about a quarter of a mile northeast of the terminus of the branch railroad and some 200 feet above it. The tunnel extends northeastward through a heavy bed of sandstone a distance of 750 feet, where the upper coal is encountered. From the end of the tunnel entries extend northwest and southeast

[a] Lakes, Arthur, The Book Cliff coal mines. Mines and Minerals, vol. 24, 1904, p. 289.

about 800 feet in each direction, and several rooms have been opened up the rise. The tunnel not only avoids climbing a precipitous ledge, but has a distinct advantage over an opening on the outcrop. A gravity incline can thus be operated and the workings can be pushed along the strike and up the rise, avoiding, in the early stage of development at least, a haul up the dip, which in this mine is very steep. In the workings the coal bed dips from 25° to 30° N. 55° E., and is traversed by prominent joint planes, the most conspicuous of which strikes between N. 65° E. and N. 75° E. The bed averages about 7 feet thick, with a parting of sandstone, varying from one-fourth inch to 3 inches in thickness, about 3 feet from the top. The output of the mine for 1905 was reported as 6,000 tons.

The Cameo mine, operated by the Grand Junction Mining and Fuel Company, is situated at the mouth of a small creek which enters Grand River about 4 miles above Palisades. The mine is connected with the Denver and Rio Grande Railroad by a short spur. A number of cabins, a store, a shop, etc., have been constructed and water is supplied by a steam pump from a well near the river.

The coal worked is the upper or Cameo bed. At the entrance to the mine the coal is covered by a few feet of alluvium, and the bed is reached by a slope. Nine feet or more of coal is exposed, but only 5 or 6 feet is worked. The roof is a firm sandy shale, but owing to a number of partings the coal is dirty and is reported to produce about 30 per cent of slack. The mine has been in operation eight or nine years and the workings are extensive. The entries run northwest-southeast and the rooms extend northeast and southwest, both up and down the slope. The inclination of the coal is reported to be only about 3°, so that mules can pull the cars anywhere, but the workings are at such a distance from the mouth that much time is lost in transit. Some water is encountered, but when it is reached in going down the dip the workings are abandoned. It is proposed to introduce pumps and a system of electric lighting and haulage. The annual product of the mine is reported to be 24,000 tons.

The Palisade mine is located in the face of the cliffs about 150 feet above the valley, a mile northeast of the town of Palisades. The property is controlled by the Palisade Coal and Supply Company, which began operations about 1895. A short spur connects the terminus of the gravity tramway that leads to the mine with the Denver and Rio Grande Railroad. The mine is located on the outcrop and the workings extend in about 1,600 feet. The lower coal, or Palisades bed, is worked, which averages in the mine about 3 feet 10 inches thick. No trouble is caused by water. The average output of the mine is reported to be 18,000 tons a year, about 35 per cent of which is slack.

The Carbonera mine has been in operation only two years (1906) and its output is used exclusively by the Uintah Railway Company. The mine is situated on the hillside above West Salt Creek, at the little mining settlement of Carbonera, where there are a few cabins, a shop, etc. Good mountain water is hauled from Atchee and stored in a cistern. The entrance is on the outcrop and the main entry is about 600 feet long. The roof and floor are a firm sandy shale. About 5 feet of coal is mined. Two streaks of bone, from 1 inch to 1 foot in thickness, are present, so that the coal is dirty. The daily production is reported to be about 14 tons throughout the year.

The other mines and prospects in the area under consideration are small. They are all situated on the outcrop, and the workings at the largest are only a few hundred feet in extent. They are operated only during the winter months to supply the needs of near-by settlers.

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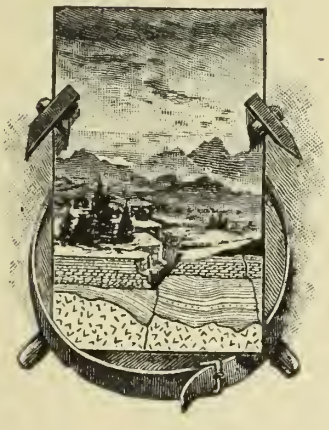

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23. Description of the Milwaukee quadrangle, Wisconsin.—U. S. Geol. Survey, Geol. Atlas of U. S., folio no. 140, 12 pp., 9 figs., 2 maps, 1 illustrations sheet, 1906.

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24. A new fossil *Busycon* (*Fulgur*) from Florida.—Nautilus, vol. 20, no. 11, p. 121, 1 pl., March, 1907.

25. Some new Eocene fossils from Alabama.—Nautilus, vol. 21, no. 1, pp. 8–11, 1 pl., May, 1907.

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26. The mines of the Altar district, Sonora.—Eng. and Min. Jour., vol. 83, pp. 653–654, 2 figs., April 6, 1907.

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27. On wollastonite and pseudo-wollastonite, polymorphic forms of calcium metasilicate, with optical study by Fred Eugene Wright.—Am. Jour. Sci., 4th ser., vol. 21, pp. 89–108, 2 figs., February, 1906.

Describes experimentation upon wollastonite, natural and artificial, the results obtained, and their optical characters.

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29. Esquisse géographique du Cap Cod (États-Unis).—Annales de Géog., Ann. 15, no. 84, pp. 443–448, 1 pl., 1 fig., November 15, 1906.

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30. The Pocahontas coals, Pottsville series no. XII, in Raleigh and Wyoming counties of West Virginia.—Min. Mag., vol. 13, no. 3, pp. 201–213, 7 figs., March, 1906.

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31. Geology of the Buck Mountain coal bed.—Eng. and Min. Jour., vol. 83, pp. 668–670, 2 figs., April 6, 1907.

32. The so-called new supplies of anthracite [Pennsylvania].—Eng. and Min. Jour., vol. 84, pp. 500–503, 4 figs., September 14, 1907.

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Amador, Manuel G.

33. Los principales centros auriferos del mundo. Estudio sobre la producción actual del oro.—Soc. cient. "Antonio Alzate," Mem. y Rev., t. 23, pp. 355–381, 1906.

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34. Report of a general committee and of six special committees of the San Francisco Association of members of the American Society of Civil Engineers. The effects of the San Francisco earthquake of April 18, 1906, on engineering constructions.—Am. Soc. Civil Eng., Proc., vol. 33, no. 3, pp. 299–354, 31 pls., 3 figs., March, 1907. Discussion by Edwin Duryea, and others, ibid., vol. 33, no. 5, pp. 537–547, 1 pl., May, 1907; Trans., vol. 59, pp. 208–329, 1907.

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36. Bibliography of Canadian geology and paleontology for the year 1904.—Canada, Roy. Soc., Proc. and Trans., 2d ser., vol. 11, sect. 4, pp. 127–152, 1906.

37. Notes on an interesting collection of fossil fruits from Vermont, in the Museum of the Geological Survey of Canada.—Ottawa Naturalist, vol. 20, no. 1, pp. 15–17, April, 1906.

Ami, Henry M.—Continued.

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39. Preliminary lists of organic remains [collected by Mr. A. P. Low from Beechey Island, Southampton Island, and Cape Chidley].—Cruise of the Neptune, pp. 329–336, 1906 (see Low, no. 1623).

40. On some fossils from northern Canada, collected by Commander Low, during the expedition of 1903–4, together with notes on the geological horizons to which they belong.—Abstract: Science, new ser., vol. 23, p. 973, June 29, 1906.

41. Preliminary lists of organic remains from the Chazy, Black River, Trenton, and Pleistocene formations comprised within the area of the Pembroke sheet (no. 122).—Geol. Survey of Canada, Appendix to Ells's Report on the Geology and Natural Resources of the northwest quarter-sheet, no. 122, pp. 47–71, 1907.

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43. Memorial of A. R. C. Selwyn.—Abstract: Science, new ser., vol. 25, pp. 763–764, May 17, 1907.

Ami, Henry M., and **Wilson**, W. J.

44. Report of the geological branch of the Ottawa Field-Naturalists' Club for 1905–6.—Ottawa Naturalist, vol. 19, no. 11, pp. 209–214, February, 1906.

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45. Studies in the development of certain Paleozoic corals.—Jour. Geology, vol. 15, no. 1, pp. 59–69, 8 figs., 1907.

46. Development of the inner wall in Paleozoic corals.—Abstract: Science, new ser., vol. 25, p. 184, February 1, 1907.

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47. Earth flaws at the time of the San Francisco earthquake.—Abstract: Science, new ser., vol. 25, p. 769, May 17, 1907.

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Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Cal.—See Arnold and Anderson, no. 67.

Metamorphism by combustion of the hydrocarbons in the oil-bearing shale of California.—See Arnold and Anderson, no. 68.

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48. Recent volcanic eruptions in the West Indies.—Congr. géol. intern., C. R. 10^{e} sess., Mexico, 1906, pp. 735–737, 13 pls., 1907.

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49. Solifluction, a component of subaerial denudation.—Jour. Geology, vol. 14, no. 2, pp. 91–112, 5 figs., 1906.

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50. Explicación del plano geologico de la región de San Pedro de Gallo, Estado de Durango [Mexico].—Mexico, Inst. Geol., Parergones, t. 2, no. 1, pp. 5–14, 1 pl. (geol. map), 1907.

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52. Notas geologicas sobre el Cretaceo en el Estado de Colima [Mexico].—Mexico, Inst. Geol., Parergones, t. 2, no. 1, pp. 29–35, 1 pl., 1907.

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Anonymous papers. See page 208.

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53. Geology of Black Hawk County [Iowa].—Iowa Geol. Survey, vol. 16, pp. 407–452, 1 pl., 4 figs., geol. map, 1906.

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55. The Yak mining, milling, and tunneling company [Leadville, Colo.].—Colorado School of Mines, Bull., vol. 4, no. 1, pp. 71–88, 10 figs., 1907.

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56. Geological reconnaissance of the coast of the Olympic Peninsula, Washington.—Geol. Soc. America, Bull., vol. 17, pp. 451–468, 4 pls., 4 figs., 1906.

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57. The Tertiary and Quaternary pectens of California.—U. S. Geol. Survey, Prof. Paper no. 47, 264 pp., 53 pls., 2 figs., 1906.

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58. Coal in the Mount Diablo Range, Monterey County, Cal.—U. S. Geol. Survey, Bull. no. 285, pp. 223–225, 1 fig., 1906.

Describes the geologic structure of the range, the relations of the coal bed, and the properties of the coal.

59. The Salt Lake oil field near Los Angeles, Cal.—U. S. Geol. Survey, Bull. no. 285, pp. 357–361, 1 fig., 1906.

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60. New and characteristic species of fossil mollusks from the oil-bearing Tertiary formations of southern California.—U. S. Nat. Mus., Proc., vol. 32, pp. 525–546, 14 pls., June 15, 1907.

61. Dome structure in conglomerate.—Jour. Geology, vol. 15, no. 6, pp. 560–570, 8 figs., 1907.

Describes the structure of domes in conglomerate near Pasadena, Cal., and discusses the origin of dome structure.

62. Fossils of the oil-bearing formations of southern California.—U. S. Geol. Survey, Bull. no. 309, pp. 219–256, 17 pls., 1907.

Gives figures of characteristic species of fossils, chiefly Pelecypoda and Gastropoda from Tertiary horizons of southern California.

Arnold, Ralph—Continued.

63. Geology and oil resources of the Summerland district, Santa Barbara County, Cal.—U. S. Geol. Survey, Bull. no. 321, 93 pp., 17 pls., 3 figs., 1907.

64. The Santa Maria oil district, California.—Abstract: Science, new ser., vol. 25, p. 825, May 24, 1907.

The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California.—See Eldridge and Arnold, no. 779.

Arnold, Ralph, and **Anderson**, Robert.

65. Diatomaceous deposits of northern Santa Barbara County, Cal.—U. S. Geol. Survey, Bull. no. 315, pp. 438–447, 1907.

66. Preliminary report on the Santa Maria oil district, Santa Barbara County, Cal.—U. S. Geol. Survey, Bull. no. 317, 69 pp., 2 pls., 1 fig., 1907.

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67. Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Cal.—U. S. Geol. Survey, Bull. no. 322, 161 pp., 26 pls., 1907.

68. Metamorphism by combustion of the hydrocarbons in the oil-bearing shale of California.—Jour. Geology, vol. 15, no. 8, pp. 750–758, 2 figs., 1907.

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69. Cannel coal in the United States.—Min. World, vol. 23, pp. 90–92, 381–383, 8 figs., 1905.

70. An area of faulting in central Pennsylvania.—Abstract: Science, new ser., vol. 23, p. 33, January 5, 1906.

71. Clearfield coal field, Pennsylvania.—U. S. Geol. Survey, Bull. no. 285, pp. 271–275, 1 fig., 1906.

Describes the geologic structure of the field and the character and occurrence of the coal beds.

72. Notes on clays and shales in central Pennsylvania.—U. S. Geol. Survey, Bull. no. 285, pp. 442–444, 1906.

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73. The geological prelude to the San Francisco earthquake.—Pop. Sci. Monthly, vol. 69, no. 1, pp. 69–75, 6 figs., July, 1906.

Gives an account of the geologic structure and geologic history of California.

74. The maximum deposition of coal in the Appalachian coal field.—Econ. Geology, vol. 1, no. 8, pp. 788–793, 1906.

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75. The maximum rate of deposition of coals.—Econ. Geology, vol. 2, no. 1, pp. 34–47, 5 figs., 1907.

From the study of peat bogs and field study of coal basins endeavors to determine the rate of accumulation of coal.

76. Were the Appalachian and eastern interior coal fields ever connected?—Econ. Geology, vol. 2, no. 7, pp. 659–666, 1907.

The Punxsutawney and Glen Campbell coal fields of Indiana and Jefferson counties, Pa.—See Peck and Ashley, no. 1888.

Correlation of coals.—See White and Ashley, no. 2549.

Ashley, George Hall, and **Glenn**, Leonidas Chalmers.

77. Geology and mineral resources of part of the Cumberland Gap coal field, Kentucky.—U. S. Geol. Survey, Prof. Paper no. 49, 239 pp., 40 pls., 13 figs., 1906.

Describes the physiography, stratigraphy, and geological structure of the region, and in detail the occurrence, character, geological relations, and correlations of the coal seams.

Ashworth, James.

78. Notes on the Crows Nest coal field, British Columbia.—Manchester Geol. and Min. Soc., Trans., vol. 29, pt. 3, pp. 78–83, 1905; Can. Min. Rev., vol. 25, no. 5, pp. 165–167, December, 1905; Eng. and Min. Jour., vol. 81, pp. 711–712, April 14, 1906.

Gives notes upon the character of the coal field and upon the rock slide at Frank, Alberta.

Atkin, Austin J. R.

79. Some further considerations on the genesis of the gold deposits of Barkerville, British Columbia, and vicinity.—Geol. Mag., dec. 5, vol. 3, no. 11, pp. 514–516, 1 fig., November, 1906.

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80. Red Mountain, Arizona: a dissected volcanic cone.—Jour. Geology, vol. 14, no. 2, pp. 138–146, 6 figs., 1906.

Describes the volcanic material of which the cone consists, the relations of the deposits to one another, and the physiographic features and geologic history of the cone.

81. The glaciation of the Uinta Mountains.—Jour. Geology, vol. 15, no. 8, pp. 790–804, 4 figs., 1907.

Aubury, Lewis E.

82. Report of the State mineralogist [California].—California State Min. Bur., Rept. of Board of Trustees, pp. 13–17, 1902.

An administrative report.

83. Report of the State mineralogist [California].—California State Min. Bur., Rept. of Board of Trustees, pp. 9–14, 1904.

An administrative report.

84. Report of the State mineralogist [California].—California State Min. Bur., Rept. of Board of Trustees, pp. 8–19, 1906.

An administrative report.

85. The copper resources of California.—California State Min. Bur., Bull. no. 23, 282 pp., pls., figs., maps, 1902.

86. The quicksilver resources of California.—California State Min. Bur., Bull. no. 27, 273 pp., 50 pls., 94 figs., 8 maps, 1903.

87. The structural and industrial materials of California.—California State Min. Bur., Bull. no. 38, pp. 13–378, 149 figs., 1906.

Ayres, W. S.

88. Deutschman's cave, near Banff, British Columbia, Canada.—Am. Inst. Min. Eng., Bi-Mo. Bull., no. 13, pp. 93–112, 17 figs., January, 1907.

Describes the location, the character of the rocks in which it has been cut, the mode of its formation, and various features of the cave.

89. Report on the exploration of Deutschman cave [British Columbia].—Canada, Dept. of the Interior, Rept. Surveyor-General for 1906, pp. 117–120, 1907.

90. Supplementary report on the additional exploration of Deutschman cave [British Columbia].—Canada, Dept. of the Interior, Rept. Surveyor-General for 1906, pp. 121–126, 1 pl., 1907.

Babcock, E. J.

91. The uses and value of North Dakota clays.—North Dakota State Geol. Survey, 4th Bienn. Rept., pp. 191–243, 1 pl., 1906.

Clay and its properties, with special reference to North Dakota clays.—See Clapp and Babcock, no. 471.

Babcock, E. J., and Clapp, C. H.

92. Economic geology of North Dakota clays.—North Dakota State Geol. Survey, 4th Bienn. Rept., pp. 95–189, 8 pls., 1906.

Bagg, Rufus M., jr.

93. The minerals of Maguarichic [Mexico].—Eng. and Min. Jour., vol. 80, pp. 2–3, 4 figs., July 6, 1905.

Gives notes on the geology of the region, and the occurrence and character of selenite, fluorite, and calcite crystals.

94. Fault breccia veins in the Sierra Madrè [Mexico].—Min. and Sci. Press, vol. 92, p. 125, 4 figs., February 24, 1906.

Discusses the origin of these mineral-bearing lodes.

Bailey, Gilbert E.

95. The saline deposits of California.—California State Min. Bur., Bull. no. 24, 216 pp., pls., figs., maps, 1902.

96. The desert: its resources, water supply, and development.—Min. World, vol. 23, no. 17, pp. 471–473, map, October 28, 1905.

Describes the physical features of the desert region of southern California, Nevada, and Arizona.

97. The borax deposits of California.—Min. World, vol. 24, no. 1, pp. 4–5, 7 figs., January 6, 1906.

Bailey, L. W.

98. The gypsum deposits of New Brunswick.—Canada, Roy. Soc., Proc. and Trans., 2d ser., vol. 12, sec. 4, pp. 3–14, 7 pls., 1906. Abstract: Science, new ser., vol. 23, pp. 971–972, June 29, 1906.

Describes the geologic occurrence and relations of the gypsum beds of New Brunswick, particularly those in the vicinity of Hillsborough, and discusses the origin of the gypsum deposits.

Bain, H. Foster.

99. Zinc and lead deposits of the upper Mississippi Valley.—U. S. Geol. Survey, Bull. no. 294, 155 pp., 16 pls., 45 figs., 1906; Wisconsin Geol. and Nat. Hist. Survey, Bull. no. 19, 155 pp., 45 figs., 18 pls. (in atlas), 1906.

Gives a historical sketch of the development of the field, describes the topography, stratigraphy, and geologic structure, the character, occurrence, and relations of the ore deposits, and the mining developments, and discusses the origin of the ores.

100. [The coals of Illinois.].—Illinois State Geol. Survey, Bull. no. 3, pp. 9–19, 1 pl., 1906.

Gives various data regarding the coal fields of Illinois. Includes a geologic map showing the distribution of the coal measures.

101. A Nevada zinc deposit.—U. S. Geol. Survey, Bull. no 285, pp. 166–169, 1906.

Describes the geologic structure of Spring Mountains, and the character and occurrence of the ore bodies, and discusses the origin of the ores.

102. The southeastern Illinois oil field.—Min. and Sci. Press, vol. 92, p. 326, May 19, 1906.

Describes the occurrence and character of oil in this area.

103. A persistent error.—Science, new ser., vol. 23, p. 919, June 15, 1906.

Calls attention to the misuse of the terms "Des Moines" and "Missourian" applied to coal measures of the western interior States.

104. Sedi-genetic and igneo-genetic ores.—Econ. Geology, vol. 1, no. 4, pp. 331–339, 1906.

Presents a classification of the metal production of the United States according to the mode of concentration of the ores, with a discussion of the data used.

Bain, H. Foster—Continued.

105. What should appear in the report of a state geologist?—Econ. Geology, vol. 1, no. 5, pp. 484–487, no. 7, pp. 702–705, 1906.

106. Some relations of paleogeography to ore deposition in the Mississippi Valley.—Congr. géol. intern., C. R. 10e sess., Mexico, 1906, pp. 483–499, 1907. Econ. Geology, vol. 2, no. 2, pp. 128–144, 1907.

Discusses concentration of metals in sedimentary rocks, and more especially the concentration of zinc and lead ores of the Mississippi Valley as affected by geographic conditions prevailing during Paleozoic sedimentation.

107. [Review of] Special report on lead and zinc, by E. Haworth and others (Kansas Univ. Geol. Survey, vol. 8).—Econ. Geology, vol. 2, no. 2, pp. 186–192, 1907.

108. The work of the [Illinois] State Geological Survey.—Western Soc. Engrs., Jour., vol. 12, pp. 233–239, April, 1907; Illinois Soc. Engrs. and Surveyors, 22d Ann. Rept., pp. 51–56, 1907.

109. Petroleum in Illinois.—Eng. and Min. Jour., vol. 83, pp. 755–756, 2 figs., April 20, 1907.

110. Administrative report for 1906.—Illinois State Geol. Survey, Bull. no. 4, pp. 9–35, 1 pl., 1907. [Also issued separately.]

Includes notes on economic resources.

111. Analysis of certain silica deposits.—Illinois State Geol. Survey, Bull. no. 4, pp. 185–186, 1907.

112. Contributions to the study of coal.—Illinois State Geol. Survey, Bull. no. 4, pp. 187–188, 1907.

113. The mineral industry in 1906 [Illinois].—Illinois State Geol. Survey, Bull. no. 4, pp. 245–246, 1907.

The production in the United States in 1905 of zinc and lead ores.—See no. 2418.

Baker, H. P.

114. The holding and reclamation of sand dunes and sand wastes by tree planting.—Iowa Acad. Sci., Proc., vol. 13, pp. 209–214, 1906.

Describes the origin of dunes.

Baker, J. Willard.

115. Monograph on meteorites.—Mineral Collector, vol. 12, no. 6, pp. 81–87, no. 7, pp. 97–103, 1905.

Baker, M. B.

116. Clay and the clay industry of Ontario.—Ontario, Bureau of Mines, Rept. 1906, vol. 15, pt. 2, 127 pp., 71 figs., 1906.

Baldacci, L.

117. Il giacimento solfifero della Louisiana. [The sulphur deposits of Louisiana.]—Italia, Ministero di Agricoltura, Industria e Commercio, Publicazioni del Corpo reale delle Miniere, Roma, Tipografia Nazionale di G. Bertero, 1906. 43 pp., 9 pls.

Baldwin, A. L.

The earth movements in the California earthquake of 1906.—See Hayford and Baldwin, no. 1114.

Ball, Sydney H.

118. Pre-Cambrian rocks of the Georgetown quadrangle, Colorado.—Am. Jour. Sci., 4th ser., vol. 21, pp. 371–389, May, 1906.

Describes the topography and general geology, and the occurrence, character, and relations of the pre-Cambrian formations.

Ball, Sydney H.—Continued.

119. Notes on ore deposits of southwestern Nevada and eastern California.—U. S. Geol. Survey, Bull. no. 285, pp. 53–73, 1 fig., 1906.

Describes the general geology, the occurrence and character of gold and silver ores, and the mining developments.

120. A geologic reconnaissance in southwestern Nevada and eastern California.—U. S. Geol. Survey, Bull. no. 308, 218 pp., 3 pls., 17 figs., 1907.

Describes the general stratigraphy of the area examined, the topography, structure, and stratified and igneous rocks of the various ranges, with notes on the character and occurrence of the economic minerals.

121. Copper deposits of the Hartville uplift, Wyoming.—U. S. Geol. Survey, Bull. no. 315, pp. 93–107, 1907.

122. The Hartville iron-ore range, Wyoming.—U. S. Geol. Survey, Bull. no. 315, pp. 190–205, 1 fig., 1907.

Describes the stratigraphy and geologic structure of the area, and the occurrence and origin of the iron ores.

123. Titaniferous iron ore of Iron Mountain, Wyoming.—U. S. Geol. Survey, Bull. no. 315, pp. 206–212, 1907.

124. Portland cement materials in eastern Wyoming.—U. S. Geol. Survey, Bull. no. 315, pp. 232–244, 2 figs., 1907.

125. Mica in the Hartville uplift, Wyoming.—U. S. Geol. Survey, Bull. no. 315, pp. 423–425, 1907.

126. Graphite in the Haystack Hills, Laramie County, Wyoming.—U. S. Geol. Survey, Bull. no. 315, pp. 426–428, 1907.

Bancroft, George J.

127. The formation and enrichment of ore-bearing veins.—Am. Inst. Min. Eng., Bi-Mo. Bull., no. 15, pp. 499–522, 1907.

128. Ore deposition.—Min. and Sci. Press, vol. 95, pp. 580–581, November 9, 1907.

Barbour, Erwin Hinckley.

129. Notice of a new fossil mammal from Sioux County, Nebraska.—Nebraska Geol. Survey, vol. 2, pt. 3, 4 pp., 1 pl., 1905.

Describes *Syndyoceras cooki* n. gen. and n. sp. from the Loup Fork beds at Agate, Nebraska.

130. Notice of a new fossil rhinoceros from Sioux County, Nebraska.—Nebraska Geol. Survey, vol. 2, pt. 4, pp. 311–318, 5 figs., 1906.

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131. Evidence of loess man in Nebraska.—Nebraska Geol. Survey, vol. 2, pt. 6, pp. 329–348, 16 figs., 1907.

132. Report on the Honey Creek coal mine.—Nebraska Geol. Survey, vol. 2, pt. 7, pp. 349–364, 7 figs., 1907.

133. Biennial report.—Nebraska Geol. Survey, vol. 2, pt. 8, pp. 365–387, 1907.

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134. Report of the tenth geological expedition of Hon. Charles H. Morrill, season of 1905.—Science, new ser., vol. 23, pp. 114–115, January 19, 1906.

135. The skull of *Syndyoceras*.—Abstract: Science, new ser., vol. 23, pp. 288–289, February 23, 1906; Am. Assoc. Adv. Sci., Proc., vol. 55, pp. 378, 1906.

136. The skulls of *Syndyoceras* and *Protoceras*.—Abstract: Science, new ser., vol. 23, p. 623, April 20, 1906.

Barbour, Erwin Hinckley—Continued.

137. A workable bed of coal in Nebraska.—Science, new ser., vol. 24, pp. 51–52, July 13, 1906.

Notes the discovery of workable coal near Peru, Nebr., its character, and other occurrences of coal in Nebraska.

138. Notice of a new Miocene rhinoceros, *Diceratherium arikarense*.—Science, new ser., vol. 24, pp. 780–781, 2 figs., December 14, 1906.

139. Report on the geological expedition of Hon. Charles H. Morrill. Season of 1906.—Science, new ser., vol. 25, pp. 73–74, January 11, 1907.

140. Evidence of man in the loess of Nebraska.—Science, new ser., vol. 25, pp. 110–112, January 18, 1907.

Announces the discovery of human remains in undisturbed loess, detailing the circumstances and conditions of preservation.

141. Prehistoric man in Nebraska.—Putnam's Monthly, pp. 413–415, 502–503, 3 figs., January, 1907.

Describes the finding of human remains in undisturbed loess deposits.

Barbour, Erwin Hinckley, and Ward, Henry Baldwin.

142. Preliminary report on the primitive man of Nebraska.—Nebraska Geol. Survey, vol. 2, pt. 5, pp. 317–327, 4 figs., 1906.

Barker, F. L.

143. Structural geology at Leadville [Colorado].—Mines and Minerals, vol. 28, no. 5, pp. 220–222, 3 figs., December, 1907.

Describes the geological relations and occurrence of the ore deposits.

Barlow, Alfred Ernest.

144. Report on some of the undeveloped zinc deposits of British Columbia.—Canada, Dept. of the Interior, Mines Branch, Report of the Commission to investigate the zinc resources of British Columbia, pp. 273–293, 4 pls., 1906.

Includes notes on the geology of the area examined.

145. On the Quebec side of Lake Timiskaming.—Canada, Geol. Survey, Summ. Rept. for 1906, pp. 113–118, 1906.

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146. On the nickel deposits of Webster, western North Carolina.—Canadian Min. Inst., Jour., vol. 9, pp. 303–316, 1 pl. (map), 1906.

Describes the occurrence of the ores and their geological relations and origin.

147. On the origin and relations of the nickel and copper deposits of Sudbury, Ontario, Canada.—Econ. Geology, vol. 1, no. 5, pp. 454–466; no. 6, pp. 545–553, 1906.

Gives a historical résumé of the literature, and describes the character of the nickel-bearing eruptive rock, and the composition and mode of occurrence of the ore bodies.

Report of a special committee on the correlation of the pre-Cambrian rocks of the Adirondack Mountains, the "original Laurentian area" of Canada, and eastern Ontario.—See Adams and others, no. 13.

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150. Origin and significance of the Mauch Chunk shale.—Geol. Soc. America, Bull., vol. 18, pp. 449–476, 4 pls., 1 fig., December, 1907. Abstract: Science, new ser., vol. 25, p. 766, May 17, 1907.

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158. Cement and cement materials [of Virginia].—In Watson, T. L., Mineral Resources of Virginia, pp. 86–167, 10 pls., 14 figs., 1907.

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159. Some unusual rocks from Maine.—Jour. Geology, vol. 14, no. 3, pp. 173–187, 2 figs., 1906.

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Describes the distribution, utilization, general character, and mode of occurrence of the limestones of Knox County, Me.

161. Clays of the Penobscot Bay region, Maine.—U. S. Geol. Survey, Bull. no. 285, pp. 428–431, 1906.

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163. Feldspar and quartz deposits of southeastern New York.—U. S. Geol. Survey, Bull. no. 315, pp. 394–399, 1907.

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177. Fauna of the Salem limestone: Brachiopoda.—Indiana, Dept. Geol. and Nat. Res., 30th Ann. Rept., pp. 1297–1322, illus, 1906.

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184. A brief review of the South Pass gold district, Fremont County, Wyo. Second edition, July 15, 1904. 16 pp.

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186. Mineral and allied resources of Albany County, Wyoming. Laramie, Wyoming, 1906. 80 pp., illus.

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187. The mines of Bolanos, old Mexico.—California Jour. Tech., vol. 10, no. 4, pp. 11–14, November, 1907.

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192. Cobalt district and northward.—Canada, Geol. Survey, Summ. Rept. for 1906, pp. 110–112, 1906.

Gives notes on the occurrence of the ores containing silver, nickel, and cobalt.

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201. Distribution of the coal beds of the State [of Illinois].—Illinois State Geol. Survey, Bull. no. 3, pp. 19–25, 1 pl., 1906.

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202. The Peabody atlas. Shipping mines and coal railroads of the central commercial district of the United States, accompanied by chemical, geological, and engineering data. Chicago, published by Peabody Coal Company, 1906. 149 pp., maps and illustrations.

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213. A brief sketch of fossil plants.—New Jersey Geol. Survey, Ann. Rept. State Geol. for 1905, pp. 97–133, 8 figs., 1906.

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236. Report of the director of the survey [Wisconsin].—Wisconsin Geol. and Nat Hist. Survey, Fifth Bienn. Rept. of the Commissioners, pp. 9–35, 1906.

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246. The geologic distribution of the road materials of Indiana.—Indiana, Dept. Geol. and Nat. Res., 30th Ann. Rept., pp. 120–160, 1906.

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248. The natural resources of the State of Indiana.—Indiana, Dept. Geol. and Nat. Res., 31st Ann. Rept., pp. 13–72, 3 pls., 1907.

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[Boileau, John W.]

253. Coal fields of southwestern Pennsylvania, Washington and Greene counties. Fields of coking coal located in eastern Greene and southeastern Washington counties, Pa., owned and largely controlled by Mr. J. V. Thompson. Copyright, September, 1907, by John W. Boileau. 90 pp., map and illustrations.

Includes a description of the geologic structure of the area.

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254. The soils of St. Mary's County [Maryland].—Maryland Geol. Survey, St. Mary's County, pp. 125–146, 1907.

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255. The soils of Calvert County [Maryland].—Maryland Geol. Survey, Calvert County, pp. 135–167, 1907.

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256. Les mines d'or de la Californie.—Revue univ. des Mines, 3e sér., t. 53, pp. 30–82, 245–307, 1901.

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257. Sobre algunas faunas terciarias de México.—México, Inst. Geol., Bol., no. 22, 97 pp., 12 pls., 1906.

Describes Mollusca from Tertiary beds of Mexico.

258. La fauna de Moluscos del Senoniano de Cárdenas, San Luis Potosí [México].—México, Inst. Geol., Bol., no. 24, 95 pp., 18 pls., 1906.

Discusses stratigraphic position and correlation of the beds from which the fauna described was derived, and gives systematic descriptions of the Mollusca.

259. Excursions à Chavarrillo, Santa Maria Tatetla, Vera Cruz, et Orizaba [México].—Xe Congr. géol. intern., Guide des Excursions, Mexico, no. II, 11 pp., 1 pl., 1906.

Describes the geology of the country along the route traveled.

260. Excursions aux mines de soufre de la Sierra de Banderas [México].—Xe Congr. géol. intern., Guide des Excursions, Mexico, no. XIX, 8 pp. 2 figs., 1906.

Describes the occurrence of sulphur deposits.

261. Excursion au Cerro de Muleros près ciudad Juarez (Chihuahua).—Xe Congr. géol. intern., Guide des Excursion, Mexico, no. XX, 24 pp., 6 pls. (incl. geol. map and sections), 1906.

262. Excursion dans les environs de Parras [México].—Xe Congr. géol. intern., Guide des Excursions, Mexico, no. XXIII, 16 pp., 6 pls. (incl. geol. map and sections).

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Böse, Emilio—Continued.

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265. Excursion à l'Isthme de Tehuantepec.—X^{e} Congr. géol. intern., Guide des Excursions, Mexico, no. XXXI, 40 pp., 1 pl., 1906.

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266. Nota preliminar sobre la fauna pliocénica de Santa María Tatetla, Ver.—Soc. Geol. Mexicana, Bol., t. 2, no. 2, pp. 51–64, 1906.

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267. Sobre algunos fósiles pleistocénicos recogidos por el Sr. Dr. E. Angermann en la Baja California.—Mexico, Inst. Geol., Parergones, t. 2, no. 2, pp. 41–45, 1907.

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268. Un appareil perfectionné pour la reproduction photographique des sutures d'ammonites et d'ambulacres des oursins.—Soc. cient. "Antonio Alzate," Mem. y Rev., t. 24, no. 12, pp. 467–475, 4 figs., June, 1907.

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344. [Review of] Zinc and lead deposits of the Upper Mississippi Valley, by H. F. Bain (U. S. Geol. Survey, Bull. no. 294).—Econ. Geology, vol. 2, no. 6, pp. 617–624, 1907.

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347. Brachiopod nomenclature.—Science, new ser., vol. 24, pp. 742–743, December 7, 1906.

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The San Francisco earthquake of April 18, 1906, as recorded by the Coast and Geodetic Survey magnetic observations.—See Bauer and Burbank, no. 169.

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351. The Clinton or red ores of the Birmingham district, Alabama.—U. S. Geol. Survey, Bull. no. 315, pp. 130–151, 1907.

352. The brown iron ores of the Russellville district, Alabama.—U. S. Geol. Survey, Bull. no. 315, pp. 152–160, 1907.

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Burckhardt, Carlos.

357. Géologie de la Sierra de Concepción del Oro [México].—X^{e} Congr. géol. intern., Guide des Excursions, Mexico, no. XXIV, 24 pp., geol. map, 1906.

358. Géologie de la Sierra de Mazapil et Santa Rosa [México].—X^{e} Congr. géol. intern., Guide des Excursions, Mexico, no. XXVI, 40 pp., 17 pls. (incl. 2 geol. maps), 1906.

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360. Sobre el descubrimiento del Trias marino en Zacatecas.—Soc. Geol. Mexicana, Bol., t. 2, pp. 43–45, 1906.

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362. Sur le climat de l'époque jurassique.—Soc. cient. "Antonio Alzate," Mem. y Rev., t. 25, no. 1, pp. 45–49, July, 1907.

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365. The Lluvia de Oro district, Mexico.—Min. and Sci. Press, vol. 94, pp. 664–667, 4 figs., May 25, 1907.

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366. Ligero estudio sobre los pozos de "El Ébano," explotados por la Mexican Petroleum Co.—Soc. Geol. Mexicana, Bol., t. 2, pp. 111–131, 1 pl., 1906.

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369. The Warrior coal basin in the Birmingham quadrangle, Alabama.—U. S. Geol. Survey, Bull. no. 285, pp. 211–222, 1 pl. (map), 1906.

Describes the stratigraphy and structure of the field; the occurrence, character, and relations of the coal seams; and the character and composition of the coal.

370. Limestone and dolomite in the Birmingham district, Alabama.—U. S. Geol. Survey, Bull. no. 315, pp. 247–255, 1907.

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374. The possibilities of Salton Sea.—Pop. Sci. Monthly, vol. 70, no. 1, pp. 5–18, 20 figs., January, 1907.

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Caballero, Gustavo de J.

375. La región geisseriana al N. de Estado de Michoacán [México].—Soc. cient. "Antonio Alzate," Mem. y Rev., t. 22, pp. 203–208, 1905.

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376. Los yacimientos de fierro del Carrizal, Estado de Nuevo Leon [México].—Soc. cient. "Antonio Alzate," Mem. y Rev., t. 22, pp. 183–186, 1905.

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378. Some old Mexican volcanoes.—Scottish Geog. Mag., vol. 23, no. 6, pp. 281–312, 26 figs., June, 1907.

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Cairnes, D. D.—Continued.

380. Explorations in a portion of the Yukon south of Whitehorse.—Canada, Geol. Survey, Summ. Rept. for 1906, pp. 22–30, 1906.

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381. Moose Mountain district of southern Alberta.—Canada, Geol. Survey, 55 pp., 3 pls., 2 maps, 1907.

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382. Recent developments in mining in the southern Yukon.—Canadian Min. Jour., vol. 28 (new ser., vol. 1), pp. 87–88, 121–122, 1907.

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Calderón, Salvador.

383. Sobre los fenomenos de las pegas.—México, Secretaría de Fomento, Bol., 2ª época, año 6, VI, no. 10, pp. 141–158, May, 1907; Congr. géol. intern., C. R. 10e sess., Mexico, 1906, pp. 1187–1200, 1907.

Discusses contact phenomena.

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384. The Montana lobe of the Keewatin ice sheet.—U. S. Geol. Survey, Prof. Paper no. 50, 62 pp., 7 pls., 31 figs., 1906.

Describes briefly the physiography and general geology of northern Montana, and in detail the character and occurrence of the surface formations, with discussion of the distribution of mountain glaciers and the Keewatin ice sheet and their inter-relations as shown by the drift deposits, and of the drainage with changes produced by the ice.

California State Earthquake Investigation Commission.—See Lawson and others, no. 1531.

California State Mining Bureau.

385. Register of mines and minerals, with map [of each of the following counties, issued separately]:

Amador County, by John B. Tregloan, 17 pp., 1903.
Butte County, by W. E. Thorne, 13 pp., 1903.
Calaveras County, by W. H. H. Penniman, 50 pp., 1900.
El Dorado County, by J. E. Armstrong, 32 pp., 1902.
Inyo County, by A. V. Davidson, 24 pp., 1902.
Kern County, by Marion Aubury, 37 pp., 1904.*
Lake County, by George Madeira, 14 pp., 1901.
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509. Autophytographs.—Abstract: Elisha Mitchell Sci. Soc., Jour., vol. 22, no. 3, p. 58, 1906.

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510. Rhætic flora of Moncure shales.—Abstract: Elisha Mitchell Sci. Soc., vol. 22, no. 3, p. 60, 1906.

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511. Where the wind does the work.—Nat. Geog. Mag., vol. 17, no. 6, pp. 310–317, 10 figs., June, 1906; Elisha Mitchell Sci. Soc., Jour., vol. 22, no. 3, pp. 80–85, 1906.

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514. The origin of the horse.—Nature, vol. 70, pp. 53–54, 1904.

515. The snails of New Mexico and Arizona.—Nautilus, vol. 19, no. 6, pp. 68–71, October, 1905.

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517. A new Tertiary *Planorbis*.—Nautilus, vol. 19, no. 9, pp. 100–101, January, 1906.

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519. A fossil water-bug.—Canadian Entomologist, vol. 38, no. 6, p. 209, June, 1906.

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520. The fossil fauna and flora of the Florissant (Colorado) shales.—Colorado Univ., Studies, vol. 3, no. 3, pp. 157–175, 1 pl., 1906.

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525. A new fly (fam. Mycetophilidæ) from the Green River beds.—Am. Jour. Sci., 4th ser., vol. 23, pp. 285–286, 1 fig., April, 1907.

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531. A fossil caterpillar [from the Miocene shales of Florissant, Colorado].—Canadian Entomologist, vol. 39, no. 6, pp. 187–188, June, 1907.

532. A fossil butterfly of the genus *Chlorippe*.—Canadian Entomologist, vol. 39, no. 11, pp. 361–363, 1 pl., November, 1907.

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533. A fossil Tortricid moth.—Canadian Entomologist, vol. 39, no. 12, p. 416, December, 1907.

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534. A fossil tsetse-fly in Colorado.—Nature, vol. 76, p. 414, August 22, 1907.

535. A Miocene wasp.—Nature, vol. 77, p. 80, November 28, 1907.

536. A new zonitoid shell from the Miocene, Florissant, Colorado.—Nautilus, vol. 21, no. 8, p. 89, December, 1907.

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An investigation into the elastic constants of rocks, more especially with reference to cubic compressibility.—See Adams and Coker, nos. 10, 11.

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537. C. L. Herrick as a maker of scientific men.—Denison Univ., Sci. Lab., Bull., vol. 13, art. 1, pp. 1–13, 1 pl. (port.), 1905.

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538. Durham County: geological features.—First Report of the Bureau of Archives for the Province of Ontario, 1903, pp. 46–47, 1 fig., 1904.

539. The Sudbury nickel field.—Ontario, Bur. Mines, Rept., 1905, vol. 14, pt. 3, 188 pp., illus., 1905.

Describes the general geology, the occurrence, character, and relations of the ore deposits, and the character and distribution of eruptive rocks, of Huronian sediments, and of Pleistocene deposits, and gives an account of the petrography of the nickel eruptive, of the economic developments of the field, and of the minerals found in the Sudbury nickel district of Ontario.

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Discusses, with regard to the report of the special committee of American and Canadian geologists on the nomenclature of the formations of the Lake Superior region, the relationships of various pre-Cambrian formations in the upper lakes region of Canada and their nomenclature.

541. The Helen iron mine, Michipicoten.—Econ. Geology, vol. 1, no. 6, pp. 521–529, 4 figs., 1906.

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542. Iron ranges of eastern Michipicoten.—Ontario, Bur. Mines, Rept., 1906, vol. 15, pt. 1, pp. 173–199, 13 figs., 1 map, 1906.

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543. Magmatic segregation of sulphide ores.—Abstract: British Assoc. Adv. Sci., Rept. 75th meeting, p. 400, 1906.

544. A lower Huronian ice age.—Am. Jour. Sci., 4th ser., vol. 23, pp. 187–192, March, 1907. Abstract: Science, new ser., vol. 25, p. 769, May 17, 1907.

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545. The need of field work in the study of ore genesis.—Eng. and Min. Jour., vol. 83, pp. 295–296, February 9, 1907.

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547. Interglacial periods in Canada.—Congr. géol. intern., C. R. 10e sess., Mexico, 1906, pp. 1237–1258, 1907.

548. Iron ranges east of Lake Nipigon.—Ontario, Bur. Mines, 16th Ann. Rept., vol. 16, pt. 1, pp. 105–135, 15 figs., 1907.

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550. Copper deposits in the Belt formation in Montana.—Econ. Geol., vol. 2, no. 6, pp. 572–575, 1907.

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551. Mica and the mica industry.—Franklin Inst., Jour., vol. 161, no. 1, pp. 43–58, 5 figs., January, 1906; no. 2, pp. 81–100, 6 figs., February, 1906. Reprinted in book form: The Franklin Institute, Philadelphia, 1906. 130 pp., 36 figs.

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552. Geology and coal resources of the Cape Lisburne region, Alaska.—U. S. Geol. Survey, Bull. no. 278, 54 pp., 9 pls., 8 figs., 1906.

Describes the geography, the stratigraphy, embracing Devonian, Carboniferous, and Mesozoic formations and Quaternary deposits, and in detail the coal resources of Jurassic and Carboniferous age.

553. Ore deposits in the St. Joe River basin, Idaho.—U. S. Geol. Survey, Bull. no. 285, pp. 129–139, 1 pl., 1 fig., 1906.

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555. The Arkansas coal field.—U. S. Geol. Survey, Bull. no. 316, pp. 137–160, 1 pl., 1907.

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Collins, Edgar A.

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558. A prospecting shaft in the Goldfield district, Goldfield, Nevada.—Inst. Min. and Metall., Trans., vol. 15, pp. 540–542, 1906.

Describes the geology and occurrence of the ore bodies.

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559. Notes on the wollastonite rock mass, and its associated minerals, of the Santa Fé mine, State of Chiapas, Mexico.—Min. Mag., vol. 13, pp. 356–362, December, 1903.

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560. [Report on] the Lake Superior region between the Pic and Nipigon rivers.—Canada, Geol. Survey, Summ. Rept. for 1905, pp. 80–82, 1906.

Gives notes upon the physical features and general geology of the area examined.

561. On surveys along the National Transcontinental Railway location between Lake Nipigon and Lac Seul.—Canada Geol. Survey, Summ. Rept. for 1906, pp. 103–109. 1906.

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Colorado, State Bureau of Mines.

562. Report of the State Bureau of Mines for the years 1905–6. 127 pp., illus., 1907.

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563. Geological notes.—Southern California Acad. Sci., Bull., vol. 1, pp. 74–77, 1902.

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564. The U. S. Geological Survey.—Science, new ser., vol. 25, pp. 309–311, February 22, 1907.

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565. A new fossil pinniped (*Desmatophoca oregonensis*) from the Miocene of the Oregon coast.—Oregon Univ. Bull., Suppl. to vol. 3, no. 3, 14 pp., 2 pls., 3 figs., May, 1906.

Condra, George Evart.

566. Observations on glacial accumulations of Nebraska.—Abstract: Science, new ser., vol. 23, p. 620, April 20, 1906.

567. Oil and gas possibilities in Nebraska.—Abstract: Science, new ser., vol. 23, p. 621, April 20, 1906.

568. A new limestone in the Indian Territory.—Abstract: Science, new ser., vol. 23, p. 624, April 20, 1906.

569. Geography of Nebraska. Lincoln, Nebraska, The University Publishing Co., 1906. 192 pp., 118 figs.

Describes physiographic features.

570. Geology and water resources of the Republican River Valley and adjacent areas, Nebraska.—U. S. Geol. Survey, W.-S. and Irrig. Paper, no. 216, 71 pp., 13 pls., 3 figs., 1907.

571. Opening of the Indian Territory.—Am. Geog. Soc., Bull., vol. 39, no. 6, pp. 321–340, 9 figs., June, 1907.

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572. Procés-verbaux des séances générales.—Compte Rendu de la X^{e} session, Mexico, 1906, pp. 108–156, 1907.

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Connecticut, State Geological and Natural History Survey.

573. Second biennial report of the commissioners, 1905–1906. Hartford Press, 1906. 23 pp.

An administrative report.

Cook, C. W.

Datolite from Westfield, Massachusetts.—See Kraus and Cook, no. 1426.

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Cooper, W. F.

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Corey, G. W.

577. The Nonesuch sandstone.—Eng. and Min. Jour., vol. 82, p. 778, 1 fig., October 27, 1906.

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Corkill, E. T.

578. Mines of Ontario.—Ontario, Bur. Mines, Rept., 1906, vol. 15, pt. 1, pp. 47–107, 35 figs., 1906.

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579. Mica in Ontario.—Canadian Min. Jour., vol. 28, no. 9 (new ser., vol. 1, no. 7), pp. 196–200, 6 figs., June 15, 1907.

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580. Alaska and its possibilities.—Am. Min. Congr., Rept. of Proc., 9th Ann. Sess., pp. 260–263, 1907.

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Coste, Eugene.

581. Natural gas and petroleum [in Ontario].—Ontario, Bur. Mines, Rept. 1906, vol. 15, pt. 1, pp. 108–115, 1906.

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584. The Cobalt mining district.—Eng. and Min. Jour., vol. 82, pp. 5–6, 5 figs., July 7, 1906.

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Courtis, W. M.

586. Gold in Michigan.—Michigan State Board of Geol. Survey, Rept. for 1906, pp. 581–584, 1907.

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587. Some features of the great earthquake.—Sci. Am., vol. 94, p. 383, May 12, 1906.

Craig, E. H. Cunningham.

588. Geological structure of Trinidad.—Imperial Inst., Bull., vol. 5, no. 2, pp. 175–179, 1907.

Crandall, Albert R.

589. The coals of the Big Sandy Valley, south of Louisa and between Tug Fork and the headwaters of the north fork of Kentucky River.—Kentucky Geol. Survey, Bull. no. 4, 141 pp., 30 pls., 1905.

Describes the general geology and topography of the area, the occurrence, character, thickness, and relations of the coal seams, giving numerous sections, and the character and composition of the coals.

Crandall, Roderic.

590. The Cretaceous stratigraphy of the Santa Clara Valley region in California.—Am. Jour. Sci., 4th ser., vol. 24, pp. 33–54, 3 figs., July, 1907.

Describes the occurrence of Cretaceous formations and gives lists of the fossils found in different exposures.

591. The geology of the San Francisco Peninsula.—Am. Philos. Soc., Proc., vol. 46, no. 185, pp. 3–58, 1 pl. (map), 3 figs. and sections, 1907.

Describes the geologic formations and the petrography of their rocks, the geologic structure and physiographic features, and the earth movements in the San Francisco earthquake of April 18, 1906.

Crane, W. R.

592. Asphaltic coals in the Indian Territory: forms of the deposits, methods of prospecting and mining.—Mines and Minerals, vol. 26, no. 6, pp. 252–254, 6 figs., January, 1906.

Describes the distribution, relations, and character of the coal deposits.

Crane, W. R.—Continued.

593. Lead and zinc mining in the Quapaw district, Oklahoma.—Mines and Minerals, vol. 27, no. 9, pp. 445–446, 1 fig., May, 1907.

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Crespi, R. A.

594. Geology and development of Aguacate mines, Costa Rica.—Min. World, vol. 27, pp. 847–848, November 9, 1907.

Crider, A. F.

595. Geology and mineral resources of Mississippi.—U. S. Geol. Survey, Bull. no. 283, 99 pp., 4 pls., 5 figs., 1906.

Describes the occurrence, character, and relations of Devonian, Mississippian, Cretaceous, Tertiary, and Quaternary formations, and the mineral resources, mainly clays and cement materials.

596. Clays of western Kentucky and Tennessee.—U. S. Geol. Survey, Bull. no. 285, pp. 417–427, 1 pl., 1906.

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597. Drainage of wet lands in Arkansas by wells.—U. S. Geol. Survey, W.-S. and Irrig. Paper no 160, pp. 54–58, 1 fig., 1906.

598. Cement and Portland cement materials of Mississippi.—Mississippi State Geol. Survey, Bull. no. 1, 73 pp., 6 pls., 1907.

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599. Summary of the underground-water resources of Mississippi.—U. S. Geol. Survey, W.-S. and Irrig. Paper no. 159, 86 pp., 6 pls., 11 figs., 1906.

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600. The making of the Grand Canyon of the Colorado.—Pop. Sci. Monthly, vol. 69, pp. 417–424, 7 figs., November, 1906.

Crosby, William O.

The limestone-granite contact deposits of Washington Camp, Arizona.—Am. Inst. Min. Eng., Trans., vol. 36, pp. 626–646, 1906 (Bi-Mo. Bull. no. 6, pp. 1217–1238, 1905).—See Crosby, 16, page 78 of Bulletin no. 301, U. S. Geol. Survey.

601. Ore deposits of the eastern gold belt of North Carolina.—Tech. Quart., vol. 20, no. 3, pp. 280–286, September, 1907.

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602. Volcanic action in Alaska.—Science, new ser., vol. 26, p. 78, July 19, 1907.

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603. Prowersose (syenitic lamprophyre) from Two Buttes, Colorado.—Jour. Geology, vol. 14, no. 3, pp. 165–172, 1906.

Describes the occurrence, the macroscopic and microscopic characters, and the chemical composition, and compares it with similar rocks.

604. Stratigraphic results of a reconnaissance in western Colorado and eastern Utah.—Jour. Geology, vol. 15, no. 7, pp. 634–679, 11 figs., 1907.

Discusses the correlation of Cretaceous, Jurassic, Triassic, and Carboniferous formations.

Cross, Whitman—Continued.

605. Memoir of George H. Eldridge [1854–1905].—Geol. Soc. America, Bull., vol. 17, pp. 681–687, 1907.

Gives also a list of his publications.

606. Methods of igneous intrusion.—Abstract: Science, new ser., vol. 25, pp. 621–622, April 19, 1907.

Glacial phenomena of the San Juan Mountains, Colorado.—See Howe and Cross, no. 1247.

Cross, Whitman, **Howe**, Ernest, and **Irving**, J. D.

• 607. Description of the Ouray quadrangle [Colorado].—U. S. Geol. Survey, Geol. Atlas of U. S., folio no. 153, 20 pp., 4 figs., 2 maps, structure-section and illustration sheets, 1907.

Describes the topography, the character, occurrence, and relations of Algonkian, Devonian, Carboniferous, Triassic, Cretaceous, Tertiary, and Quaternary deposits, and of igneous surface and intrusive rocks, geologic structure and history, and the economic resources, chiefly gold, silver, and coal.

Cross, Whitman, **Iddings**, J. P., **Pirsson**, L. V., **Washington**, H. S.

608. The texture of igneous rocks.—Jour. Geology, vol. 14, no. 8, pp. 692–707, 7 figs., 1906.

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Cumings, Edgar R.

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610. Description of the Bryozoa of the Salem limestone of southern Indiana.—Indiana, Dept. Geol. and Nat. Res., 30th Ann. Rept., pp. 1274–1296, illus., 1906.

611. Gasteropoda, Cephalopoda, and Trilobita of the Salem limestone.—Indiana, Dept. Geol. and Nat. Res., 30th Ann. Rept., pp. 1335–1375, illus., 1906.

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612. Fauna of the Salem limestone of Indiana: Introduction.—Indiana, Dept. Geol. and Nat. Res., 30th Ann. Rept., pp. 1189–1201, 6 pls., 1906.

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Curtis, George Carroll.

613. Looking into the Caribbean craters. A personal narrative of ascents to the active craters of La Soufrière and Pelée.—The Century Magazine, vol. 65, no. 3, pp. 420–434, 10 figs., January, 1903.

Cushing, H. P.

614. Geology of the Long Lake quadrangle.—New York State Mus., Bull. 115, pp. 451–531, 20 pls., 2 figs., geol. map, 1907.

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615. How faults should be named and classified.—Econ. Geology, vol. 2, no. 4, pp. 433–435, 1 fig., June, 1907.

616. Asymmetric differentiation in a bathylith of Adirondack syenite.—Geol. Soc. America, Bull., vol. 18, pp. 477–492, 1 pl., December, 1907. Abstract: Science, new ser., vol. 25, p. 774, May 17, 1907.

617. Physical oscillations during the Cambro-Silurian in northeastern New York.—Abstract: Science, new ser., vol. 26, p. 403, September 27, 1907.

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Report of a special committee on the correlation of the pre-Cambrian rocks of the Adirondack Mountains, the "original Laurentian area" of Canada, and eastern Ontario.—See Adams and others, no. 13.

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618. Types in the paleontological collections of the Boston Society of Natural History.—Boston Soc. Nat. Hist., Proc., vol. 33, no. 6, pp. 249–275, May, 1907.

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619. The extraordinary faulting at the Berlin Mine, Nevada.—Am. Inst. Min. Eng., Bi-Mo. Bull., no. 14, pp. 331–344, 5 figs., March, 1907; Eng. and Min. Jour., vol. 83, pp, 617–621, 6 figs., March 30, 1907.

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620. The geological history of Mount Greylock [Massachusetts]. Pittsfield, Massachusetts, 1906. 17 pp., 5 figs.

621. Slate deposits and slate industry of the United States.—U. S. Geol. Survey, Bull. no. 275, 154 pp., 25 pls., 15 figs., 1906.

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622. Note on a new variety of Maine slate.—U. S. Geol. Survey, Bull no. 285, pp. 449–450, 1906.

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623. The granites of Maine. With an introduction by George Otis Smith.—U. S. Geol. Survey, Bull. no. 313, 202 pp., 14 pls., 39 figs., 1907.

624. Recent work on New England granites.—U. S. Geol. Survey, Bull. no. 315, pp. 356–359, 1907.

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625. Slate deposits of the United States.—U. S. Geol. Survey, Bull. no. 275, pp. 51–125, 18 pls., 12 figs., 1906.

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Dall, William Healey.

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2210. Notes on glaciation in the Sangre de Cristo Range, Colorado.—Jour. Geology, vol. 15, no. 1, pp. 15–22, 6 figs., 1907.

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2242. The paragenesis of the minerals in the glaucophane-bearing rocks of California.—Am. Philos. Soc., Proc., vol. 45, pp. 183–242, 1906.

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2255. Magnetic observations in geological and economic work. I.—Econ. Geology, vol. 2, no. 4, pp. 367–379, 5 figs., June, 1907.

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2397. The times and places of earthquakes.—Pop. Sci. Monthly, vol. 68, no. 6, pp. 537–542, June, 1906.

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2399. The ore deposits of Copperopolis, California.—Econ. Geology, vol. 2, no. 8, pp. 797–799, 1907.

2400. The sodium nitrate deposits of the Colorado.—Min. and Sci. Press, vol. 94, pp. 634–635, 4 figs., May 18, 1907.

2401. Faulting in the Red Cloud mine [Idaho].—Min. and Sci. Press, vol. 95, pp. 747–748, 3 figs., December 14, 1907.

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2402. A simple classification of igneous rocks.—Min. and Sci. Press, vol. 94, pp. 404–405, March 30, 1907.

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2403. San Francisco's great disaster.—Philadelphia, P. W. Ziegler Co., 1906. 424 pp., illus.

Includes a chapter by R. S. Tarr on earthquakes and their causes. See no. 2355.

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2404. A Canadian Department of Mines or Geological Survey.—Canadian Min. Inst., Jour., vol. 9, pp. 107–111, 1906.

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2407. The origin of the small sand mounds in the Gulf coast country.—Science, new ser., vol. 23, pp. 849–851, June 1, 1906.

Describes occurrence and character of these mounds and suggests hypotheses for their explanation.

2408. Report on a geological survey of the lands belonging to the New York and Texas Land Company (Ltd.), in the upper Rio Grande embayment in Texas.—Augustana Library Publications, Rock Island, Ill., no. 6, pp. 51–107, 7 pls., 1 map, 1907.

2409. A sketch of the geology of the Chisos country, Brewster County, Texas.—Univ. of Texas, Bull. no. 93 (Sci. ser. no. 11), 101 pp., April 15, 1907.

Describes the physiography of the region, the occurrence, character, relations, and economic value of Ordovician, Carboniferous, Cretaceous, and Tertiary strata, and of igneous rocks, the geologic structure and history, and the mineral resources, particularly quicksilver and coal.

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2410. The Delafield drill core [Illinois].—Illinois State Geol. Survey, Bull. no. 4, pp. 203–211, 1907.

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2411. Systematic paleontology of the Pleistocene deposits of Maryland: Molluscoidea.—Maryland Geol. Survey, Pliocene and Pleistocene, pp. 210–212, 2 figs., 1906.

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2413. The evolution of the horse.—Delaware County Institute of Science, vol. 2, no. 4, pp. 115–127, 2 figs., July, 1907; Sci. Am. Suppl., vol. 64, pp. 412–414, 5 figs., December 28, 1907.

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2414. Areal geology of the lower Clear Creek (Colorado).—Colorado Univ., Studies, vol. 3, no. 4, pp. 263–376, 5 figs., 1906; Colorado Sci. Soc., Proc., vol. 8, pp. 103–122, 5 figs., 1906.

Describes the topography, the general geology, and the occurrence, characters, and relations of the metamorphosed igneous rocks occupying the area.

Upham, Warren.

2415. Quaternary history of the upper Mississippi Valley.—Abstract: Geol. Soc. America, Bull., vol. 17, pp. 725–726, 1907.

U. S. Department of Agriculture, Bureau of Soils.

2416. Soil survey field book. Field season, 1906. 319 pp.

Contains a classification of soils.

Field operations of the Bureau of Soils.—See Whitney, nos. 2570, 2571.

U. S. Geological Survey.

2417. The San Francisco earthquake and fire of April 18, 1906, and their effects on structures and structural materials.—U. S. Geol. Survey, Bull. no. 324, 170 pp., 57 pls., 2 figs., 1907.

Contains the following papers:

Preface, by Joseph A. Holmes, pp. xi–xii.
The earthquake as a natural phenomenon, by G. K. Gilbert, pp. 1–13.
The effects of the earthquake and fire on various structures and structural materials, by Richard L. Humphrey, pp. 14–61.
The effects of the earthquake and fire on buildings, engineering structures, and structural materials, by John S. Sewell, pp. 62–130.
The earthquake and fire and their effects on structural steel and steel-frame buildings, by Frank Soulé, pp. 131–158.
List of papers relating to the earthquake and fire, pp. 159–161.

2418. Mineral resources of the United States, calendar year 1905, 1403 pp., 1906.

Contains the following papers, largely statistical in character, relating to the production, condition of the industry, etc., but also in some cases containing notes on the geology and occurrence of the products treated:

Mineral products of the United States in 1904 and 1905, pp. 23–41.
Value, by States, of mineral products in 1905, by Wm. Taylor Thom, pp. 42–52.

(Metals.)

Antimony, by C. C. Schnatterbeck, pp. 435–439.
Bismuth, by C. C. Schnatterbeck, pp. 441–443.
Copper, by Charles Kirchhoff, pp. 343–362.
Gold and silver, by Waldemar Lindgren and others, pp. 113–341.
Production in the United States, by Waldemar Lindgren, pp. 113–127.
Alaska, by Alfred H. Brooks, pp. 127–134.
Arizona, by V. C. Heikes, pp. 134–162.
California, by Charles G. Yale, pp. 162–185.
Colorado, by Waldemar Lindgren, pp. 185–214.
Idaho, by V. C. Heikes, pp. 214–242.
Montana, by Alexander N. Winchell, pp. 242–259.
Nevada, by Charles G. Yale, pp. 259–275.

U. S. Geological Survey—Continued.
Gold and silver—Continued.
New Mexico, by Waldemar Lindgren, pp. 275–284.
Oregon, by Charles G. Yale, pp. 284–293.
South Dakota, by Waldemar Lindgren, pp. 293–297.
Southern Appalachian States, including Alabama, Georgia, Maryland, North Carolina, South Carolina, and Tennessee, by Waldemar Lindgren, pp. 297–304.
Texas, by Waldemar Lindgren, pp. 304–305.
Utah, by V. C. Heikes, pp. 305–331.
Washington, by Charles G. Yale, pp. 331–337.
Wyoming, by Waldemar Lindgren, pp. 337–341.
Iron ores, by John Birkinbine, pp. 53–87.
Lead, by Charles Kirchhoff, pp. 363–370.
Manganese ores, by John Birkinbine, pp. 87–111.
Platinum, by F. W. Horton, pp. 423–434.
Quicksilver, by F. W. Horton, pp. 393–404.
Silver. See Gold and silver.
Steel-hardening metals, by Joseph Hyde Pratt, pp. 405–421.
Tin, by Frank L. Hess, pp. 445–451.
Zinc, by Charles Kirchhoff, pp. 371–377.
Zinc and lead ores, by H. Foster Bain, pp. 379–392.

(Fuels.)

Coal, by Edward W. Parker, pp. 453–714.
Coke, by Edward W. Parker, pp. 715–766.
Gas, coke, tar, and ammonia at gas works and in retort coke ovens, by Edward W. Parker, pp. 767–797.
Natural gas, by W. T. Griswold, pp. 799–812.
Petroleum, by W. T. Griswold, pp. 813–920.

(Structural materials.)

Cement:
Advance in cement technology, by Edwin C. Eckel, pp. 921–923.
Statistics of cement industry, by L. L. Kimball, pp. 924–944.
Clay-working industries, by Jefferson Middleton, pp. 945–1002.
Lime and sand-lime brick, by Edwin C. Eckel, pp. 1003–1006.
Sand and gravel, by A. T. Coons, pp. 1007–1010.
Slate, pp. 1011–1020.
Stone industry, by A. T. Coons, pp. 1021–1067.

(Abrasive materials.)

Abrasive materials, by Joseph Hyde Pratt, pp. 1069–1085.

(Chemical materials.)

Arsenious oxide, by C. C. Schnatterbeck, pp. 1087–1089.
Borax, by Charles G. Yale, pp. 1091–1096.
Bromine, by Frederick J. H. Merrill, pp. 1097–1098.
Fluorspar and cryolite, by Edmund Otis Hovey, pp. 1099–1103.
Gypsum and gypsum products, by Edwin C. Eckel, pp. 1105–1115.
Phosphate rock, by Edmund Otis Hovey, pp. 1117–1126.
Salt, by Edmund Otis Hovey, pp. 1127–1135.
Sulphur and pyrite, pp. 1137–1143.
Barytes, pp. 1145–1146.
Mineral paints, pp. 1147–1154.

(Miscellaneous.)

Asbestos, by George Otis Smith, pp. 1155–1159.
Asphaltum and bituminous rock, by Edmund Otis Hovey, pp. 1161–1169.
Bauxite and aluminum, pp. 1171–1174.
Black sands, by David T. Day and R. H. Richards, pp. 1175–1258.
Carbon dioxide, by Myron L. Fuller, pp. 1259–1263.
Graphite, by George Otis Smith, pp. 1265–1269.
Lithium minerals, by Edmund Otis Hovey, pp. 1271–1272.
Magnesite, by Charles G. Yale, pp. 1273–1278.
Mica, by George Otis Smith, pp. 1279–1283.
Mineral waters, by Myron L. Fuller, pp. 1285–1308.

U. S. Geological Survey—Continued.
Monazite and zircon, by Joseph Hyde Pratt, pp. 1313–1317.
Peat, by Marius R. Campbell, pp. 1319–1322.
Precious stones, by George Frederick Kunz, pp. 1323–1358.
Quartz (flint) and feldspar, by Heinrich Ries, pp. 1359–1360.
Talc and soapstone, by Joseph Hyde Pratt, pp. 1361–1368.

2419. Mineral resources of the United States. Calendar year, 1906. 1307 pp., 2 figs., 1907.

Contains the following papers, largely statistical in character, relating to the production, condition of the industry, etc., but also in some cases containing notes on the geology and occurrence of the products treated:

Introduction, by David T. Day and E. W. Parker, pp. 9–12.
Summary of mineral production of the United States in 1906, compiled by Wm. Taylor Thom, pp. 13–65.

(Metals.)

Antimony, by Frank L. Hess, pp. 511–516.
Bauxite and aluminum, by Ernest F. Burchard, pp. 501–510.
Bismuth, by Frank L. Hess, p. 517.
Chromite or chromic iron ore, by Arthur J. Collier, pp. 541–542.
Copper, by L. C. Graton, pp. 373–438.
Gold and silver, by Waldemar Lindgren and others, pp. 111–371.
  Production in the United States, by Waldemar Lindgren, pp. 111–134.
  Alaska, by Alfred H. Brooks, pp. 134–146.
  Arizona, by V. C. Heikes, pp. 147–177.
  California, by Charles G. Yale, pp. 178–198.
  Colorado, by Chester Naramore, pp. 199–240.
  Idaho, by V. C. Heikes, pp. 240–267.
  Montana, by Alexander N. Winchell, pp. 267–287.
  Nevada, by Charles G. Yale, pp. 287–300.
  New Mexico, by Chester Naramore, pp. 300–312.
  Oregon, by Charles G. Yale, pp. 312–318.
  South Dakota, by Chester Naramore, pp. 319–323.
  Southern Appalachian States, including Alabama, Georgia, Maryland, North Carolina, South Carolina, Tennessee, Virginia, by H. D. McCaskey, pp. 323–333.
  Texas, by H. D. McCaskey, pp. 333–334.
  Utah, by V. C. Heikes, pp. 334–362.
  Vermont, by H. D. McCaskey, p. 362.
  Washington, by Charles G. Yale, pp. 362–368.
  Wyoming, by Chester Naramore, pp. 368–371.
Iron ores, pig iron, and steel, by Edwin C. Eckel, pp. 67–102.
Lead, by J. M. Boutwell, pp. 439–457.
Manganese ores, by Edwin C. Eckel, pp. 103–109.
Nickel, cobalt, tungsten, vanadium, molybdenum, titanium, uranium, and tantalum, by Frank L. Hess, pp. 519–540.
Platinum, by David T. Day, pp. 551–562.
Quicksilver, by J. M. Boutwell, pp. 491–499.
Silver. See Gold and silver.
Tin, by Frank L. Hess, pp. 543–549.
Zinc, by J. M. Boutwell, pp. 459–489.

(Fuels.)

Coal, by E. W. Parker, pp. 563–753.
Coke, by E. W. Parker, pp. 755–809.
Natural gas, by B. Hill, pp. 811–826.
Petroleum, by W. T. Griswold, pp. 827–896.

(Structural materials.)

Cement:
  Advances in cement technology, 1906, by Edwin C. Eckel, pp. 897–905.
  Statistics of cement industry in 1906, by L. L. Kimball, pp. 906–931.
Clay-working industries, by Jefferson Middleton, pp. 933–983.
Glass sand, sand, and gravel, by Ernest F. Burchard, pp. 993–1000.
Lime and sand-lime brick, by Edwin C. Eckel, pp. 985–991.
Slate, by A. T. Coons, pp. 1001–1005.
Stone, by A. T. Coons, pp. 1007–1041.

U. S. Geological Survey—Continued.

(Abrasive materials.)

Abrasive materials, by Douglas B. Sterrett. pp. 1043–1054.

(Chemical materials.)

Arsenic, by Frank L. Hess, pp. 1055–1058.
Barytes, with a note on strontium, by Ernest F. Burchard, pp. 1109–1114.
Borax, by Charles G. Yale, pp. 1059–1062.
Fluorspar and cryolite, by Ernest F. Burchard, pp. 1063–1067.
Gypsum and gypsum products, by Ernest F. Burchard, pp. 1069–1078.
Mineral paints, pp. 1115–1122.
Phosphate rock and phosphorus:
  Phosphate rock, by Myron L. Fuller, pp. 1079–1084.
  Phosphorus, by George W. Stose, pp. 1084–1090.
Salt and bromide, by A. T. Coons, pp. 1091–1101.
Sulphur and pyrite, pp. 1103–1108.

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Asbestos, by J. S. Diller, pp. 1123–1129.
Asphalt and bituminous rock, by Joseph A. Taff, pp. 1131–1137.
Graphite, by George Otis Smith, pp. 1139–1143.
Magnesite, by Charles G. Yale, pp. 1145–1147.
Mica, by Douglas B. Sterrett, pp. 1149–1163.
Mineral waters, by Samuel Sanford, pp. 1165–1194.
Monazite and zircon, by Douglas B. Sterrett, 1195–1209.
Peat, by Marius R. Campbell, pp. 1211–1212.
Precious stones, by Douglas B. Sterrett, pp. 1213–1252.
Quartz (flint) and feldspar, by Edson S. Bastin, pp. 1253–1270.
Selenium, by Frank L. Hess, p. 1271.
Talc and soapstone, by Arthur J. Collier, pp. 1273–1275.

Contributions to economic geology, 1905.—U. S. Geol. Survey, Bull. no. 285, 506 pp., 13 pls., 16 figs., 1906.

The papers in this bulletin have been listed under the individual authors.

Contributions to economic geology, 1906. Part I. Metals and nonmetals, except fuels.—U. S. Geol. Survey, Bull. no. 315, 505 pp., 4 pls., 20 figs., 1907.

The papers in this bulletin have been listed under the individual authors.

Contributions to economic geology, 1906. Part II. Coal, lignite, and peat.—U. S. Geol. Survey, Bull. no. 316, 543 pp., 23 pls., 6 figs., 1907.

The papers in this bulletin have been listed under the individual authors.

Report on progress of investigations of mineral resources of Alaska in 1906.—See Brooks, A. H., and others.

Vallat, B. W.

2420. The iron ores and system of mining at Sunrise mine, Wyoming.—Colorado Sci. Soc., Proc., vol. 8, pp. 315–322, 6 pls., 1907.

Van Hise, Charles Richard.

2421. The problems of geology.—Congress of Arts and Science, Universal Exposition, St. Louis, 1904, vol. 4, pp. 525–548, 1906.

2422. The geology of the Cobalt district [Ontario].—Abstract: Canadian Min. Jour., vol. 28, no. 4 (new ser., vol. 1, no. 2), pp. 44–45, April 1, 1907.

Discusses the origin of the silver-cobalt ores, and their geologic relations.

Report of a special committee on the correlation of the pre-Cambrian rocks of the Adirondack Mountains, the "original Laurentian area" of Canada, and eastern Ontario.—See Adams and others, no. 13.

Van Horn, F. B.

2423. The mineral production of Illinois in 1905.—Illinois State Geol. Survey, 14 pp., 1906.

2424. Limestones available for fertilizers.—Illinois State Geol. Survey, Bull. no. 4, pp. 177–183, 1907.

Van Wagenen, H. R.

2425. Tungsten in Colorado.—Colorado School of Mines, Bull., vol. 3, no. 2, pp. 138–169, 2 figs., January, 1906.

Includes notes on the occurrence in Colorado of ores containing tungsten.

Vaux, George, and Vaux, William S.

2426. Les variations périodiques des glaciers, 1905. British Columbia and Alberta.—Zeitschr f. Gletscherkunde, Bd. 1, Heft 3, p. 180, 1906.

Gives a short account of the condition in 1905 of the glaciers of British Columbia and Alberta.

2427. Observations made in 1906 on glaciers in Alberta and British Columbia.—Philadelphia Acad. Nat. Sci., Proc., vol. 58, pp. 568–579, 5 pls., 1907.

2428. Observations made in 1907 on glaciers in Alberta and British Columbia.—Philadelphia, Acad. Nat. Sci., Proc., vol. 59, pt. 3, pp. 560–563, 1907.

Vaux, William S.

2429. Modern glaciers: their movements and the methods of observing them.—Philadelphia, Eng. Club, Proc., vol. 24, no. 3, pp. 259–283, 13 figs., July, 1907.

Veatch, Arthur C.

2430. On the human origin of the small mounds of the lower Mississippi Valley and Texas.—Science new ser., vol. 23, pp. 34–36, January 5, 1906.

Describes character and occurrence of these mounds and states objections to considering them of human origin.

2431. Long Island water resources.—Supplement to the Taxpayer [Brooklyn, N. Y.], April 21, 1906. 15 pp., 6 figs.

An account of the geologic structure and history of Long Island and its underground water resources.

2432. Age and type localities of the supposed Jurassic fossils collected north of Fort Bridger, Wyoming, by Frémont in 1843.—Am. Jour. Sci., 4th ser., vol. 21, pp. 457–460, June, 1906.

2433. Fluctuations of the water level in wells, with special reference to Long Island, New York.—U. S. Geol. Surv., W.-S. and Irrig. Paper no. 155, 83 pp., 9 pls., 17 figs., 1906.

2434. Outlines of the geology of Long Island [New York].—U. S. Geol. Survey, Prof. Paper no. 44, pp. 15–52, 10 pls., 20 figs., 1906.

Describes the geologic structure, the occurrence, character, and relations of Cretaceous, Tertiary, and Quaternary deposits and the geologic history of Long Island.

2435. Underground water conditions of Long Island.—U. S. Geol. Survey, Prof. Paper no. 44, pp. 53–85, 9 pls., 16 figs., 1906.

2436. Geology and underground water resources of northern Louisiana and southern Arkansas.—U. S. Geol. Survey, Prof. Paper no. 46, 422 pp., 51 pls., 33 figs., 1906.

Describes the geologic history and structure, the occurrence, character, and relations of Cretaceous, Tertiary, and Quaternary formations, the general underground water conditions and principal water-bearing horizons, and the underground water prospects by counties.

2437. Coal and oil in southern Uinta County, Wyo.—U. S. Geol. Survey, Bull. no. 285, pp. 331–353, 3 pls. (maps and sections), 1906.

Describes the stratigraphy and structure of the area and the occurrence, character, and geologic relations of coal beds and of petroleum.

2438. Geology and underground water resources of northern Louisiana with notes on adjoining districts.—Louisiana, Geol. Survey, Bull. no. 4, 209 pp., 26 pls., 18 figs., 1906.

This paper is made up of excerpts from Professional Paper no. 46 of the U. S. Geological Survey. See no. 2436.

Veatch, Arthur C.—Continued.

2439. On the origin and definition of the geologic term "Laramie."—Jour. Geology, vol. 15, no. 6, pp. 526–549, 1907. Abstract: Am. Jour. Sci., 4th ser., vol. 24, pp. 18–22, July, 1907.

2440. Coal fields of east-central Carbon County, Wyo.—U. S. Geol. Survey, Bull. no. 316, pp. 244–260, 1 pl., 1907.

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2441. Well records on Long Island.—U. S. Geol. Survey, Prof. Paper no. 44, pp. 116–337, 11 pls., 7 figs., 1906.

Veatch, Otto.

2442. The term "colluvial" as applied to clay deposits.—Science, new ser., vol. 24, p. 782, December 14, 1906.

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2443. Kaolins and fire clays of central Georgia.—U. S. Geol. Survey, Bull. no. 315, pp. 303–314, 1 fig., 1907.

Verri, A.

2444. Le eruzioni della Montagna Pelée e del vulcano Laziale.—Soc. geol. italiana, Boll., vol. 24, pp. 84–88, 1905.

Describes phenomena attending the eruption of Mont Pelé in 1902.

Verrill, Addison E.

2445. The Bermuda Islands. Part IV, Geology and paleontology, and Part V, An account of the coral reefs.—Connecticut Acad. Arts and Sci., Trans., vol. 12, pp. 45–348, 25 pls., 180 figs., 1907.

Describes the geologic structure, the occurrence and relation of the Tertiary and later deposits, the geologic history of the islands, and invertebrate fossils.

Vicaire, A.

2446. Les gisements pétrolifères des États Unis.—Soc. de l'Ind. min., St. Étienne, Bull., 4e ser., t. 4, pp. 681–849, 5 pls., 11 figs., 1905; t. 7, pp. 433–488, 3 pls., 5 figs., 1907.

An extended account of the petroleum industry and petroleum deposits of the United States.

Vigier, Victor von.

Sobre la aplicación de la potasa cáustica á la preparación de fósiles.—See Böse and Vigier, no. 269.

Villafaña, Andrés.

2447. El volcán Jorullo.—México, Inst. Geol., Parergones, t. 2, no. 3, pp. 73–130, 8 pls., 1907.

Describes situation, topography, geologic structure, and petrography of the volcano Jorullo, in Mexico.

Villarello, Juan D.

2448. Descripción de las minas "Santiago y anexas" de Estado de Michoacán [México].—Soc. cient. "Antonio Alzate." Mem. y Rev., t. 22, pp. 125–140, 3 pls., 1 fig., 1905.

Describes the geology, occurrence, and origin of the gold and silver ores.

2449. Reseña del mineral de Arzate (Estado de Durango).—Soc. cient. "Antonio Alzate." Mem. y Rev., t. 23, pp. 211–240, 1905.

Describes the geology, the mines, and the occurrence and origin of the ore deposits.

2450. Descripción de algunas minas de Zacualpan (Estado de México).—Soc. cient. "Antonio Alzate." Mem. y Rev., t. 23, pp. 251–266, 1906.

Describes the local geology, and the occurrence, character, and origin of the ore deposits.

Villarello, Juan D.—Continued.

2451. Description des mines "La Bella Union," (État de Guerrero). Génèse des gisements de mercure.—Soc. cient. "Antonio Alzate," Mem. y. Rev., t. 23, pp. 395–411, 1905.

Describes the local geology, and the occurrence, character, and origin of the mercury ores.

2452. Aplicación de la fluoresceina á cuestiones de salubridad pública.—Soc. cient. "Antonio Alzate." Mem. y Rev., t. 24, no. 2, pp. 51–62, August, 1906.

Discusses the use of fluorescein in the study of underground waters.

2453. Un nuevo fluoroscopio.—Soc. cient. "Antonio Alzate," Mem. y Rev., t. 24, no. 2, pp. 63–72, 1 fig., August, 1906.

Describes a new fluoroscope for use in the study of underground waters.

2454. Hidrología subterranea de las cercanías de Jiutepec (Estado de Morelos) [México].—Soc. cient. "Antonio Alzate," Mem. y Rev., t. 24, no. 4, pp. 159–171, October, 1906.

Discusses underground waters in the environs of Jiutepec, State of Morelos, Mexico.

2455. Le minéral de Mapimí [México].—X^{e} Congr. géol. intern., Guide des Excursions, Mexico, no. XVIII, 18 pp., 2 pls., 1906.

Describes the character, occurrence, relations, and genesis of the ore deposits.

2456. Le minéral d'Aranzazú (État de Zacatecas).—X^{e} Congr. géol. intern., Guide des Excursions, Mexico, no. XXV, 29 pp., 3 pls., 1906.

Describes the local geology, and the occurrence, character, and origin of the copper ores, and the mines.

2457. Sur le remplissage de quelques gisements métallifères.—Congr. géol. intern., C. R., 10^{e} sess., Mexico, 1906, pp. 533–553, 1907.

2458. Hidrologia subterránea de los alrededores de Querétaro [México].—México, Secretaría de Fomento, Bol., 2^{a} época, año 7, no. 4, IV, pp. 65–81; no. 5, IV, pp. 84–96, 3 pls., 1907.

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2459. Géologie chimique des gisements de soufre de Mapimí, État de Durango.—Soc. cient. "Antonio Alzate," Mem. y. Rev., t. 26, no. 4, pp. 115–145, 1907.

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Florida, Leon County, by Henry J. Wilder and others, pp. 363–388.
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Indiana, Newton County, by N. P. Neill and W. E. Tharp, pp. 747–779.
Indiana, Tippecanoe County, by N. P. Neill and W. E. Tharp, pp. 781–813.
Kansas, Brown County, by James L. Burgess and others, pp. 911–926.
Kentucky, McCracken County, by Thomas D. Rice, pp. 679–694.
Kentucky, Madison County, by A. M. Griffen and Orla L. Ayrs, pp. 659–678.
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Minnesota, Carlton area, by W. J. Geib and Grove B. Jones, pp. 815–835.

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Missouri, Crawford County, by W. Edward Hearn and Charles J. Mann, pp. 865–878.
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2579. Memoir of Albert Allen Wright [1846–1905].—Geol. Soc. America, Bull., vol. 17, pp. 687–690, 1907.

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2581. The iron concretions of the Redbank sands.—Jour. Geology, vol. 14, no. 3, pp. 243–252, 8 figs., 1906.

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Austin chalk, Cretaceous, Texas: Ries, 2058; Udden, 2408.
Aylmer formation, Ordovician, Canada: Raymond, 1987.
Bad River gabbro, Algonkian, Michigan: Gordon and Lane, 985.
Bagley andesite, Jurassic, California: Diller, 721.
Baird formation, Carboniferous, California: Diller, 721.
Balaklala rhyolite, pre-Devonian, California: Diller, 721.
Baltic conglomerate, Algonkian, Michigan: Lane, 1509.
Baltimore gneiss, Algonkian, Maryland: Clark and Mathews, 488.
Bandera shale, Pennsylvanian, Kansas: Schrader and Haworth, 2144; Wooster, 2636.
Banff limestone, Carboniferous, Alberta: Dowling, 736.
Banff shale (lower), Carboniferous, Alberta: Dowling, 736.
Banff shale (upper), Permo-Triassic, Alberta: Dowling, 736.
Bangor limestone, Carboniferous, Alabama: Butts, 370.
Bangor (Chester) limestone, Mississippian, Alabama: Smith, 2229.
Barclay limestone, Carboniferous, Kansas: Wooster, 2636.
Barkersville gabbro, Triassic?, North Carolina: Keith, 1354.
Barnwell buhr sands, Eocene, South Carolina: Sloan, 2218.

Bashi formation, Eocene, Alabama: Smith, 2229.
Bass Mountain diabase, Carboniferous, California: Diller, 721.
Battie quartzite, Cambrian, Maine: Smith *et al.*, 2241.
Bayport formation, Carboniferous, Michigan: Cooper, 575.
Bayport limestone, Michigan: Lane, 1508.
Bayport or Maxville limestone, Mississippian, Michigan: Lane, 1516.
Bays sandstone, Ordovician, Virginia: Bassler, 158.
Bearpaw shales, Cretaceous, Alberta: Cairnes, 381; Dowling, 735.
Bear River formation, Cretaceous, Wyoming: Schultz, 2151; Veatch, 2437.
Beaumont clays, Pleistocene, Texas: Fenneman, 859; Ries, 2058.
Beaver, Carboniferous, Appalachian region: Stevenson, 2295.
Beaver limestone, Cambrian, Georgia: Watson, 2483.
Becket gneiss, pre-Cambrian, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Becraft limestone, Devonian, New York: Grabau, 991.
Becraft member, Devonian, Maryland: Clark and Mathews, 488.
Bedford oolitic limestone, Mississippian, Indiana: Blatchley, 246.
Bedrock series, California: Reid, 2018.
Beech granite, Archean, North Carolina and Tennessee: Keith, 1354.
Beekmantown beds, Ordovician, New York: Ruedemann, 2097.
Beekmantown formation, Ordovician, Vermont: Seely, 2164.
Belknap dike, New Hampshire: Pirsson and Washington, 1934.
Bellepoint member of Columbus formation, Devonian, Ohio: Swartz, 2329.
Bellingham conglomerate, Massachusetts: Mansfield, 1674.
Belmont porphyry dikes, Montana: Barrell, 149.
Beloit formation, Ordovician, upper Mississippi Valley: Sardeson, 2122.
Belt group, Algonkian, Montana: Barrell, 149.
Belt terrane, Algonkian, Montana: Warner, 2477.
Benning granite, Georgia: Lindgren, 1596.
Benton formation, Cretaceous, Montana: Rowe, 2090.
Benton formation, Cretaceous, Wyoming: Veatch, 2440.
Benton group, Cretaceous, Nebraska: Condra, 570.
Benton shale, Cretaceous, Colorado: Gale, 922.
Benton shale, Cretaceous, North Dakota: Leonard, 1563.
Benton shales, Cretaceous, Alberta: Cairnes, 381.
Benwood limestone, Carboniferous, Appalachian region: Stevenson, 2295.
Benwood limestone, Carboniferous, Pennsylvania: Clapp, 475.
Benwood limestone, Carboniferous, West Virginia: Grimsley, 1046.
Berea grit, Mississippian, Michigan: Lane, 1516.
Berea sandstone, Carboniferous, Pennsylvania: Woolsey, 2634.
Berenda formation, Carboniferous, New Mexico: Keyes, 1377.
Bergman series, Cretaceous, Alaska: Brooks, 313.
Berkshire schist, Ordovician, Connecticut: Gregory and Robinson, 1038.
Berkshire (Hudson) schist, Connecticut: Gregory, 1034.
Bertie waterlime, Silurian, New York: Clarke, 494; Hartnagel, 1085; Luther, 1633.
Bethany Falls limestone, Carboniferous, Kansas: Wooster, 2636.
Bighorn limestone, Ordovician, Wyoming: Darton, 642, 644–647; Fisher, 873.
Bijiki formation, pre-Cambrian, Michigan: Lane and Seaman, 1518.
Bijiki (Ironwood), Michigan: Gordon and Lane, 985.
Binary granite, Colorado: Underhill, 2414.
Bingen sand, Cretaceous, Arkansas: Veatch, 2436.
Binnewater quartzite, Silurian, New York: Hartnagel, 1084.
Binnewater sandstone, Silurian, New York: Grabau, 991.
Birch Creek formation, pre-Devonian, Alaska: Prindle, 1956.
Birch Creek schists, Alaska: Brooks, 313.
Birmingham shale, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Black Creek shale, Cretaceous, South Carolina: Sloan, 2218.
Blackfoot formation, pre-Cambrian, Montana: Emmons, 806.
Blackfoot series, Algonkian, Montana: Walcott, 2470.
Black Hand formation, Carboniferous, Ohio: Carney, 427.
Black Mingo shales, Eocene, South Carolina: Sloan, 2218.
Black River, Ordovician, Ontario: Ells, 788.
Blackville limestone, Carboniferous, Appalachian region: Stevenson, 2295.
Bladen formation, Cretaceous, North Carolina: Stephenson, 2281.
Blanco formation, Tertiary, Texas: Gould, 986.
Bloyd shale, Pennsylvania, Arkansas: Purdue, 1971.
Blue chert series, Devonian, California: Hershey, 1133.
Bluff formation, Quaternary, Mississippi: Logan, 1608.
Boggy formation, Carboniferous, Indian Territory; Taff, 2332.

Bohemian Range group, Cambrian, Michigan: Lane and Seaman, 1518.
Bohicket marl-sand, Pleistocene, South Carolina: Sloan, 2218.
Bohio formation, Eocene, Panama: Howe, 1244.
Bolivar fire clay, Carboniferous, West Virginia: Grimsley, 1046.
Bolton schist, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Bonneterre limestone, Cambrian, Missouri: Shepard, 2194.
Boone chert, Carboniferous, Arkansas: Purdue, 1970.
Boone formation, Mississippian, Arkansas: Purdue, 1971.
Boone formation, Mississippian, Indian Territory: Taff, 2332.
Boone formation, Mississippian, Kansas: Schrader and Haworth, 2144.
Boquillas flags, Cretaceous, Texas: Udden, 2409.
Boss Mountain diabase, Carboniferous, California: Diller, 721.
Bowler formation, Triassic? and Permian, Montana: Rowe, 2090.
Bow River series, Canada: Walcott, 2470.
Boyle limestone, Devonian, Kentucky: Foerste, 884.
Bradford schist, Vermont: Richardson, 2037.
Bragdon formation, California: Hershey, 1133.
Bragdon formation, Carboniferous, California: Diller, 721.
Brainard shales, Ordovician, Iowa: Calvin, 388.
Branford granite-gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Brassfield limestone, Silurian, Kentucky: Foerste, 883, 884.
Brasstown schist, Cambrian, North Carolina: Keith, 1352.
Brayman shales, Silurian, New York: Grabau, 991.
Brentwood limestone lentil, Pennsylvania, Arkansas: Purdue, 1971.
Brevard schist, Cambrian, North Carolina and South Carolina: Keith, 1353.
Bridger group, Tertiary, Wyoming: Sinclair, 2214.
Bridger formation, Tertiary, Wyoming: Veatch, 2437.
Brier Creek marl, Oligocene, South Carolina: Sloan, 2218.
Brimfield schist, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Bristol granite-gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Brock shale, Triassic, California: Diller, 721.
Bromley formation, Ordovician, Kentucky: Bassler, 156.
Bronson beds, Carboniferous, Kansas: Wooster, 2636.
Brookfield diorite, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Brownstown formation, Cretaceous, Arkansas: Veatch, 2436.
Brush Creek limestone, Carboniferous, Pennsylvania: Stevenson, 2294.
Brush Creek limestone, Carboniferous, West Virginia: Grimsley, 1046.
Bryson formation, Carboniferous, Kentucky: Ashley and Glenn, 77.
Buchanan gravels, Pleistocene, Iowa: Arey, 53; Calvin, 388; Leonard, 1559; Macbride, 1639; Norton, 1805; Williams, 2588.
Buda limestone, Cretaceous, Texas: Udden, 2408–2409.
Buffalo sandstone, Carboniferous, Pennsylvania: Stevenson, 2294.
Buffalo sandstone, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Bully Hill rhyolite, Triassic, California: Diller, 721.
Burches Ferry marl, Cretaceous, South Carolina: Sloan, 2218.
Burden conglomerate, Ordovician, New York: Grabau, 991.
Burgen sandstone, Ordovician, Indian Territory: Taff, 2332.
Burgoon sandstone, Mississippian, Pennsylvania: Butts, 368; Woolsey, 2634.
Burke formation, Algonkian, Montana: Walcott, 2470.
Burlingame shales, Carboniferous, Kansas: Wooster, 2636.
Burlington limestone, Mississippian, Illinois: Weller, 2523.
Burlington limestones, Mississippian, Iowa: Beyer and Williams, 234.
Burlington limestone, Mississippian, Missouri: Shepard, 2194.
Burns tuff, Oligocene, Colorado: Cross *et al.*, 607.
Burro gravels and tuffs, Tertiary, Texas: Udden, 2409.
Bushberg sandstone, Mississippian, Missouri: Weller, 2519.
Butler sandstone, Carboniferous, Pennsylvania: Butts, 268; Woolsey, 2634.
Buxton formation, Pennsylvanian, Kansas: Schrader and Haworth, 2144.
Cable formation, California: Lawson, 1528.
Cacapon sandstone, Silurian, West Virginia: Grimsley, 1044.
Cache Creek group, Devonian, British Columbia: Brooks, 313.
Calciferous, Michigan: Lane, 1508.
Calciferous, Ordovician, Ontario: Ells, 788.
Calciferous formation, Ordovician, Michigan: Lane and Seaman, 1518.
Calderwood formation, Cambrian, Maine: Smith *et al.*, 2241.
Calhoun shales, Carboniferous, Kansas: Wooster, 2636.
Calvert formation, Miocene, Maryland: Clark and Mathews, 488; Shattuck, 2185, 2188, 2191; Shattuck *et al.*, 2193.
Calvert formation, Tertiary, Virginia: Clark and Miller, 489.

Calvert formation, Tertiary, Maryland and Delaware: Miller, 1749.
Cambridge limestone, Carboniferous, Pennsylvania: Butts, 368; Stevenson, 2294.
Cambridge limestone, Carboniferous, Pennsylvania, Ohio, and West Virginia: Griswold and Munn, 1048.
Cambridge limestone, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Camillus shale, Silurian, New York: Hartnagel, 1085; Luther, 1633.
Campbell's Creek limestone, Carboniferous, West Virginia: Grimsley, 1044.
Camp Creek formation, pre-Cambrian, Montana: Emmons, 806.
Camp Creek series, Algonkian, Montana: Walcott, 2470.
Camp Nelson, Ordovician, Kentucky: Miller, 1748.
Cannelton limestone, Carboniferous, West Virginia: Grimsley, 1044.
Canterbury granite-gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Cantwell formation, Tertiary, Alaska: Brooks, 313.
Canyon formation, Carboniferous, Texas: Ries, 2058.
Canyon Largo sandstones, Eocene, New Mexico: Keyes, 1388, 1390.
Capefear formation, Jurassic?, North Carolina: Stephenson, 2281.
Cape Girardeau limestone, Ordovician, Illinois: Weller, 2517, 2524.
Capitan limestone, Carboniferous, New Mexico: Keyes, 1377.
Cardiff quartzite, Algonkian, Maryland: Clark and Mathews, 488.
Cardiff shale, Devonian, New York: Luther, 1633.
Carlile formation, Cretaceous, Colorado: Darton, 648; Fisher, 869.
Carlile shale, Cretaceous, Nebraska: Condra, 570.
Carlile shale, Cretaceous, Wyoming: Darton and O'Hara, 656.
Carlyle limestone, Carboniferous, Kansas: Wooster, 2636.
Carmichaels formation, Pleistocene, Pennsylvania: Clapp, 475, 476.
Carmichaels formation, Quaternary, Pennsylvania: Butts, 368.
Carolina gneiss, Archean, North Carolina: Keith, 1352, 1354.
Carolina gneiss, Archean, North Carolina and South Carolina: Keith, 1353.
Cashaqua shale, Devonian, New York: Luther, 1633, 1634.
Cason shale, Ordovician, Arkansas: Purdue, 1970.
Cassville plant shale, Carboniferous, West Virginia: Grimsley, 1046.
Cassville shale, Carboniferous, Appalachian region: Stevenson, 2295.
Cassville shale, Carboniferous, Pennsylvania: Clapp, 475.
Castine formation, Cambrian, Maine: Smith *et al*, 2241.
Catahoula formation, Tertiary, Louisiana: Veatch, 2436, 2437.
Cathedral granite, Tertiary, Cascade Mountains: Daly, 632.
Catron formation, Carboniferous, Kentucky: Ashley and Glenn, 77.
Catskill formation, Devonian, Pennsylvania: Butts, 367.
Catskill formation, Devonian, West Virginia: Grimsley, 1044.
Catskill member, Devonian, Pennsylvania: Clapp, 475.
Catskill series, Devonian, New York: Grabau, 991.
Cave Creek gypsum, Permian, Kansas: Wooster, 2636.
Cave Springs sandstone, Carboniferous, Kansas: Wooster, 2636.
Cawood sandstone member, Carboniferous, Kentucky: Ashley and Glenn, 77.
Cayuga formation, Silurian, Maryland: Clark and Mathews, 488.
Cayuga group, Silurian, Wisconsin: Alden, 23.
Cayuta shale member, Devonian, New York: Williams, 2583.
Cedar Hill sandstones, Permian, Kansas: Wooster, 2636.
Cedar Point shales and limestones, Permian, Kansas: Wooster, 2636.
Cedar Valley limestone, Devonian, Iowa: Calvin, 387, 388.
Cedar Valley stage, Devonian, Iowa: Arey, 53; Norton, 1805.
Central City granite, Colorado: Underhill, 2412.
Central (Mine) group, Cambrian, Michigan: Lane and Seaman, 1518.
Chaco marls, Eocene, New Mexico: Keyes, 1388, 1390.
Chagrin formation, Devonian, Kentucky: Foerste, 883.
Chama clays, Miocene, New Mexico: Keyes, 1388.
Chaman series, Eocene, New Mexico: Keyes, 1390.
Chamberlain shale, Algonkian, Montana: Rowe, 2090.
Chambersburg formation, Ordovician, Virginia: Bassler, 158.
Chambersburg limestone, Ordovician, Maryland: Clark and Mathews, 488.
Chambersburg limestone, Ordovician, Pennsylvania: Stose, 2318.
Chanute shale, Pennsylvanian, Kansas: Beede and Rogers, 181; Schrader and Haworth, 2144; Wooster, 2636.
Chariton conglomerate, Pennsylvanian, Iowa: Beyer and Williams, 234.
Chatooga zone, Archean, South Carolina: Sloan, 2218.
Chattahoochee, Tertiary, Georgia: Harper, 1077.

Chattahoochee series, Miocene, Alabama: Smith, 2229.
Chattahoochee series, Tertiary, Gulf region: Smith, 2226.
Chattanooga shale, Devonian, Indian Territory: Taff, 2332.
Chauga zone, Cambrian?, South Carolina: Sloan, 2218.
Chautauqua sandstone, Carboniferous, Kansas: Wooster, 2636.
Chazy, Ordovician, Ontario: Ells, 788.
Chazy beds, Ordovician, New York, Ruedemann, 2097.
Chazy formation, Ordovician, Vermont: Seely, 2164.
Chazy limestone, Ordovician, Vermont: Edson, 774.
Chazy limestone, Ordovician, New York, Vermont, and Canada: Raymond, 1987.
Chelmsford sandstone, Canada: Coleman, 546.
Chelmsford sandstone, pre-Cambrian, Ontario: Coleman, 539.
Chemung formation, Devonian, New York: Williams, 2583.
Chemung formation, Devonian, Pennsylvania: Butts, 367; Clapp, 475, 477.
Chemung formation, Devonian, West Virginia: Grimsley, 1044.
Chemung group, Devonian, New York: Williams, 2586.
Chemung member, Devonian, Maryland: Clark and Mathews, 488.
Chemung sandstones, Devonian, New York: Luther, 1634.
Cheraw cobbles, Pleistocene, South Carolina: Sloan, 2218.
Cherokee shale, Pennsylvanian, Kansas: Schrader and Haworth, 2144; Wooster, 2636.
Cherokee shale, Pennsylvanian, Missouri: Shepard, 2194.
Cherokee zone, Cambrian?, South Carolina: Sloan, 2218.
Cherryvale shale, Pennsylvanian, Kansas: Schrader and Haworth, 2144; Wooster, 2636.
Chesapeake group, Miocene, Maryland: Clark and Mathews, 488; Shattuck, 2188, 2191; Shattuck *et al.*, 2193.
Chester formation, Mississippian, Mississippi: Crider, 595.
Chester group, Mississippian, Missouri: Shepard, 2194.
Chickamauga limestone, Ordovician, Alabama: Butts, 370.
Chickamauga limestone, Ordovician, Virginia: Bassler, 158.
Chickasaw (Wilcox) group, Eocene, Alabama: Smith, 2229.
Chico formation, Cretaceous, California: Diller, 721.
Chico series, Cretaceous, California: Crandall, 590.
Chippewa felsite, Algonkian, Michigan: Gordon and Lane, 985.
Chisna group, Devonian, Alaska: Brooks, 313.
Chisos beds, Cretaceous, Texas: Udden, 2409.
Chitistone limestone, Alaska: Brooks, 313.
Chopaka intrusive, Paleozoic, Cascade Mountains: Daly, 632.
Choptank formation, Miocene, Maryland: Clark and Mathews, 488; Shattuck, 2185, 2188, 2191; Shattuck, *et al.*, 2193.
Choptank formation, Tertiary, Virginia: Clark and Miller, 489.
Chouteau limestone, Mississippian, Illinois: Weller, 2523.
Chouteau limestone, Mississippian, Missouri: Shepard, 2194.
Chugwater formation, Triassic?, Wyoming: Darton, 642, 644–647; Fisher, 873.
Cibolo limestone, Carboniferous, Texas: Udden, 2409.
Cimarron Creek latite, Colorado: Cross *et al.*, 607.
Cimarronian series, Carboniferous, New Mexico: Keyes, 1377.
Cincinnati formation, Ordovician, Wisconsin: Alden, 23.
Cincinnatian formation, Ordovician, Illinois: Weller, 2517, 2524.
Cisco formation, Carboniferous, Texas: Ries, 2058.
Claggett formation, Cretaceous, Alberta: Cairnes, 381; Dowling, 735.
Claiborne formation, Eocene, Mississippi: Logan, 1608.
Claiborne formation, Tertiary, Louisiana and Arkansas: Veatch, 2436, 2437.
Claiborne group, Eocene, Alabama: Smith, 2229.
Claiborne group, Tertiary, Mississippi: Crider, 595; Crider and Johnson, 599.
Claiborne stage, Eocene, Louisiana: Harris, 1079.
Clallam formation, Tertiary, Washington: Arnold, 56.
Clarion sandstone, Carboniferous, Pennsylvania: Butts, 368.
Clarksburg limestone, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Claysville limestone, Carboniferous, Pennsylvania, Ohio, and West Virginia: Griswold and Munn, 1048.
Clayton formation, Tertiary, Mississippi: Crider, 595; Crider and Johnson, 599.
Clayton limestone, Eocene, Alabama: Smith, 2229.
Clayton limestone, Eocene, Mississippi: Logan, 1608.
Clear Creek gneiss, Colorado: Underhill, 2414.
Clear Fork division of the Red Beds, Permian, Texas: Case, 443.
Clermont shale, Ordovician, Iowa: Calvin, 388.
Clinch ("Medina"), Virginia: Eckel, 765.
Clinch sandstone, Ordovician, Virginia: Bassler, 158.

Clinton formation, Silurian, Maryland: Clark and Mathews, 488.
Clinton formation, Silurian, New York: Hartnagel, 1085.
Clinton formation, Silurian, West Virginia: Grimsley, 1044.
Cloverly formation, Cretaceous, Montana: Darton, 652.
Cloverly formation, Cretaceous, Wyoming: Darton, 642, 644–647; Fisher, 873.
Coastal group, Canada: Ells, 784.
Cobleskill dolomite, Silurian, New York: Clarke, 499.
Cobleskill limestone, Silurian, New York: Grabau, 991; Hartnagel, 1084.
Cobleskill waterlime, Silurian, New York: Luther, 1633.
Cochran conglomerate, Cambrian, Tennessee: Keith, 1354.
Cockeysville marble, Algonkian, Maryland: Clark and Mathews, 488.
Cockfield member, Tertiary, Louisiana and Arkansas: Veatch, 2436, 2437.
Cockfield member of Claiborne, Eocene, Louisiana: Harris, 1079.
Coeymans limestone, Devonian, New York: Grabau, 991; Hartnagel, 1084.
Coeymans member, Devonian, Maryland: Clark and Mathews, 488.
Coffeyville formation, Pennsylvanian, Kansas: Schrader and Haworth, 2144.
Coggon limestone, Devonian, Iowa: Norton, 1805.
Coldbrook group, pre-Cambrian, Canada: Ells, 784.
Coldwater series, Mississippian, Michigan: Lane, 1516.
Coldwater shale, Carboniferous, Michigan: Cooper, 575.
Coldwater group, Tertiary, Yukon Territory: Brooks, 313.
Collinsville granite-gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Colorado formation, Cretaceous, Canada: Dowling, 735.
Colorado formation, Cretaceous, Iowa: Calvin, 387.
Colorado formation, Cretaceous, Montana: Darton, 652.
Colorado formation, Cretaceous, North Dakota: Leonard, 1563.
Colorado formation, Cretaceous, Wyoming: Darton, 642, 644–647; Fisher, 873; Veatch, 2437.
Columbia clay, Quaternary, Missouri: Shepard, 2194.
Columbia formation, Mississippi: Brown, 326.
Columbia formation, Pleistocene, South Carolina: Pugh, 1963.
Columbia formation, Quaternary, Mississippi: Logan, 1608.
Columbia formation, Quaternary, Tennessee, Kentucky, and Illinois: Glenn, 971.
Columbia formation, Tertiary, Georgia: Harper, 1077.
Columbia group, Pleistocene, Maryland: Clark and Mathews, 488; Shattuck, 2185, 2188, 2191; Shattuck *et al.*, 2193.
Columbia group, Quaternary, Maryland and Delaware: Miller, 1749.
Columbia sands, Pleistocene, South Carolina: Sloan, 2218.
Columbia sands, Pleistocene, Texas: Fenneman, 859; Ries, 2058.
Columbia Ford limestone, Carboniferous, Kansas: Wooster, 2636.
Columbus formation, Devonian, Ohio: Swartz, 2329.
Columbus limestone, Devonian, Kentucky: Foerste, 883.
Columbus limestone, Devonian, Ohio: Stauffer, 2277, 2278.
Colville, Tertiary, Alaska: Brooks, 313.
Colvin limestone, Carboniferous, Appalachian region: Stevenson, 2295.
Comanche series, Cretaceous, Arkansas: Veatch, 2436.
Comanche series, Cretaceous, Colorado: Darton, 648.
Combahee shale, Oligocene, South Carolina: Sloan, 2218.
Conasauga limestone, Ordovician, Alabama: Butts, 370.
Conasauga shales, Cambrian, Georgia: Watson, 2483.
Concreto shale, Pennsylvanian, Kansas: Schrader and Haworth, 2144.
Concreto (Lane) shale, Carboniferous, Kansas: Wooster, 2636.
Conemaugh formation, Carboniferous, Pennsylvania: Butts, 368; Clapp, 475, 477; Stevenson, 2294; Woolsey, 2634.
Conemaugh formation, Carboniferous, Pennsylvania, Ohio, and West Virginia: Griswold and Munn, 1048.
Conemaugh formation, Pennsylvanian, Maryland: Clark and Mathews, 488.
Conemaugh series, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Congaree shales, Eocene, South Carolina: Sloan, 2218.
Connellsville sandstone, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Connoquenessing sandstone, Carboniferous, Pennsylvania: Butts, 368.
Cooks Mountain beds, Tertiary, Texas: Fenneman, 859.
Copley metaandesite, pre-Devonian, California: Diller, 721.
Copper Harbor conglomerates, Cambrian, Michigan: Lane and Seaman, 1518.
Cornwall shale, Devonian, New York: Hartnagel, 1084.
Cortlandt series, Ordovician, New York: Berkey, 207.
Corwin formation, Jurassic, Alaska: Collier, 552.

Corwin series, Jurassic, Alaska: Brooks, 313.
Cottonwood limestone, Carboniferous, Kansas: Beede and Rogers, 181: Wooster, 2636.
Covington group, Ordovician, Ohio and Kentucky: Bassler, 156.
Cowrun sandstone, Carboniferous, Pennsylvania: Stevenson, 2294.
Coyote formation, Carboniferous, New Mexico: Keyes, 1377.
Crab Orchard division, Silurian, Kentucky: Foerste, 883, 884.
Cranberry granite, Archean, North Carolina and Tennessee: Keith, 1354.
Crescent formation, Tertiary, Washington: Arnold, 56.
Creston quartzite, Algonkian, Montana: Walcott, 2470.
Creston quartzite, Idaho and Montana: Daly, 631.
Cripple Creek granite, Colorado: Graton, 1026.
Crown conglomerate, Cretaceous, Texas: Udden, 2409.
Crown Point limestone, Ordovician, New York: Raymond, 1987.
Crusher Hill shales and limestones, Permian, Kansas: Wooster, 2636.
Cuchara formation, Cretaceous?, Colorado: Darton, 648.
Culebra beds, Panama: Howe, 1245.
Culebra formation, Tertiary, Panama: Howe, 1244.
Curdsville, Ordovician, Kentucky: Miller, 1748.
Cutler formation, Carboniferous (Permian?), Colorado: Cross *et al*, 607.
Cuyahoga formation, Carboniferous, Ohio: Carney, 427.
Cuyuna series, Minnesota: Leith, 1557.
Cynthiana formation, Ordovician, Kentucky: Foerste, 884.
Dadina schists, Alaska: Brooks, 313.
Dakota formation, Cretaceous, Alberta: Cairnes, 381; Dowling, 735.
Dakota formation, Cretaceous, Colorado: Darton, 648; Fenneman and Gale, 863; Fisher, 869; Gale, 922.
Dakota formation, Cretaceous, Iowa: Calvin, 387; Macbride, 1639.
Dakota formation, Cretaceous, Montana: Rowe, 2090.
Dakota formation, Cretaceous, Nebraska: Condra, 570; Woodruff, 2628.
Dakota formation, Cretaceous, Wyoming: Veatch, 2440.
Dakota sandstone, Cretaceous, Colorado: Cross *et al.*, 607.
Dakota sandstone, Cretaceous, Colorado and New Mexico: Shaler, 2176.
Dakota sandstone, Cretaceous, Wyoming: Darton and O'Harra, 656.
Dakotan series, Cretaceous, New Mexico: Keyes, 1379.
Danbury granodiorite-gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Davenport, lower, sub-stage, Iowa: Norton, 1805.
Day Creek dolomite, Permian, Kansas: Wooster, 2636.
Day Point limestone, Ordovician, New York: Raymond, 1987.
Deadwood formation, Cambrian, Wyoming: Darton, 642, 644–647; Fisher, 873.
Decker Ferry limestone, Silurian, New York: Hartnagel, 1084.
Decorah shale, Ordovician, Iowa: Beyer and Williams, 234; Calvin, 388.
Deer Creek limestone, Carboniferous, Kansas: Wooster, 2636.
DeKalb limestone, Pennsylvanian, Iowa: Beyer and Williams, 234.
Dekkas andesite, Triassic, California: Diller, 721.
Delaware limestone, Devonian, Ohio: Stauffer, 2277, 2278; Swartz, 2329.
Del Rio clay, Cretaceous, Texas: Udden, 2408, 2409.
Denison formation, Cretaceous, Arkansas: Veatch, 2436.
Dennis limestone, Carboniferous, Kansas: Beede and Rogers, 181; Schrader and Haworth, 2144; Wooster, 2636.
Denver formation, Cretaceous?, Colorado: Darton, 648.
De Smet formation, Cretaceous, Wyoming: Darton, 644–647.
Des Moines formation, Carboniferous, Iowa: Calvin, 387; Savage, 2128.
Des Moines group, Pennsylvanian, Missouri: Shepard, 2194.
Des Moines stage, Pennsylvanian, Iowa: Beyer and Williams, 234.
Devil's River limestone, Cretaceous, Texas: Udden, 2408.
Devonshire formation, Bermuda Islands: Verrill, 2445.
Difficulty Creek latite, Colorado, Cross *et al.*, 607.
Dighton conglomerate, Massachusetts: Mansfield, 1674.
Dillard series, Cretaceous, Oregon: Diller, 724.
Dockum formation, Triassic, Texas: Gould, 986.
Dockum group, Triassic, Texas: Gould, 987.
Dog Creek shales, Permian, Kansas: Wooster, 2636.
Dolores formation, Triassic, Colorado: Cross, 604; Cross *et al.*, 607.
Don beds of Toronto formation, Quaternary, Canada: Coleman, 547.
Donley limestone, Carboniferous, Pennsylvania, Ohio, and West Virginia: Griswold and Munn, 1048.
Doré formation, Canada: Bell, 189.
Dothan formation, Jurassic, Oregon: Diller, 724.

Double Mountain division of the Red Beds, Permian, Texas: Case, 443.
Dresbach formation, Cambrian, Iowa: Calvin, 387.
Dresbach sandstone, Cambrian, Iowa: Beyer and Williams, 234.
Drum formation, Pennsylvanian, Kansas: Schrader and Haworth, 2144.
Drumlummon porphyry dikes, Montana: Barrell, 149.
Dry Creek shale, Devono-Silurian, Montana: Emmons, 806.
Dubuque formation, Ordovician, upper Mississippi Valley: Sardeson, 2122.
Dudley shales, Carboniferous, Kansas: Beede and Rogers, 181; Wooster, 2636.
Duffin layer, Devonian, Kentucky: Foerste, 883, 884.
Dugout clays and gravels, Tertiary, Texas: Udden, 2409.
Duluth gabbro, Algonkian, Minnesota: Abbott, 1.
Dundee limestone, Devonian, Michigan: Cooper, 575; Lane, 1516.
Dunkard formation, Carboniferous, Appalachian region: Stevenson, 2295.
Dunkard formation, Permian, Maryland: Clark and Mathews, 488.
Dunkard group, Carboniferous, Pennsylvania: Clapp, 475, 476.
Dunkard group, Carboniferous (Permian), Pennsylvania: Clapp, 477.
Dunkard series, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Eagle formation, Cretaceous, Canada: Dowling, 735.
Eagle limestone, Carboniferous, West Virginia: Grimsley, 1044.
Eagle Ford beds, Cretaceous, Texas: Udden, 2408.
Eagle Ford formation, Cretaceous, Arkansas: Veatch, 2436.
Eagle Ford formation, Cretaceous, Texas: Ries, 2058.
Eagle Pass formation, Cretaceous, Texas: Udden, 2408.
Eagle River group, Cambrian, Michigan: Lane and Seaman, 1518.
Earlham limestone, Pennsylvanian, Iowa: Beyer and Williams, 234.
Earlton limestone, Carboniferous, Kansas: Wooster, 2636.
Eastford granite-gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
East Greenwich group, early Carboniferous or late pre-Carboniferous: Emerson and Perry, 790.
Easton schist, pre-Tertiary, Washington: Smith and Calkins, 2240.
Economy member, Ordovician, Ohio and Kentucky: Bassler, 156.
Eddy formation, Carboniferous, New Mexico: Keyes, 1377.
Eden, Ordovician, Kentucky: Miller, 1748.
Eden formation, Ordovician, Ohio and Kentucky: Bassler, 156.
Eden shale, Ordovician, Pennsylvania: Stose, 2318.
Eden shales and sandstones, Ordovician, Virginia: Bassler, 158.
Edgefield-Chesterfield zone, Algongian?, South Carolina: Sloan, 2218.
Edisto marls, Miocene, South Carolina: Sloan, 2218.
Edmonton formation, Cretaceous, Alberta: Cairnes, 381.
Edmonton series, Cretaceous, Canada: Dowling, 735.
Elbert formation, Devonian, Colorado: Cross *et al.*, 607.
Elbrook limestone, Cambro-Ordovician, Pennsylvania: Stose, 2318.
Elgin sandstone, Pennsylvanian, Kansas: Schrader and Haworth, 2144; Wooster, 2636.
Elgin shaly limestones, Ordovician, Iowa: Calvin, 388.
Elk Lick limestone, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Ellensburg formation, Tertiary, Washington: Smith and Calkins, 2240.
Ellis formation, Cretaceous, Montana: Rowe, 2090.
Ellsworth schist, Cambrian or pre-Cambrian, Maine: Smith *et al.*, 2241.
Elmdale formation, Carboniferous, Kansas: Beede and Rogers, 181; Wooster, 2636.
Elm Grove limestone, Carboniferous, West Virginia: Grimsley, 1046.
Elvins formation, Cambro-Ordovician, Missouri: Shepard, 2194.
Ely greenstone, Archean, Minnesota: Abbott, 1.
Ely limestone, Carboniferous, Nevada: Lawson, 1526.
Embar formation, Carboniferous, Wyoming: Darton, 642, 647; Fisher, 873.
Empire formation, Algonkian, Montana: Walcott, 2470.
Empire shale, Algonkian, Montana: Barrell, 149.
Emporia limestone, Carboniferous, Kansas: Beede and Rogers, 181; Wooster, 2636.
Enfield shale member, Devonian, New York: Williams, 2583.
Englishtown, Cretaceous, New Jersey: Clark, 483.
Englishtown sand, Cretaceous, New Jersey: Weller, 2520.
Enochkin formation, Jurassic, Alaska: Brooks, 313.
Eo-Huronian, pre-Cambrian, Michigan: Lane and Seaman, 1518.
Erie (Bronson) beds, Carboniferous, Kansas: Wooster, 2636.
Erwin quartzite, Cambrian, North Carolina and Tennessee: Keith, 1354.
Escondido beds of Eagle Pass formation, Cretaceous, Texas: Udden, 2408.
Eskridge shales, Carboniferous, Kansas: Beede and Rogers, 181.

Esopus shales, Devonian, New York: Grabau, 991.
Estill clay, Silurian, Kentucky: Foerste, 883, 884.
Eureka beds, Carboniferous, Kansas: Wooster, 2636.
Eureka quartzite, Ordovician, Nevada and California: Ball, 120.
Eutaw formation, Cretaceous, Alabama: Smith, 2229.
Eutaw formation, Cretaceous, Mississippi: Logan, 1608.
Eutaw sands, Cretaceous, Mississippi: Crider, 595; Crider and Johnson, 599.
Eutaw sand, Cretaceous, Tennessee: Glenn, 971.
Evans granite, Colorado: Collier, 553.
Evanston formation, Tertiary, Wyoming: Schultz, 2151; Veatch, 2437.
Everton limestone, Ordovician, Arkansas and Missouri: Purdue, 1967.
Fairhaven diatomaceous earth, Miocene, Maryland: Shattuck, 2185, 2188.
Fairhaven diatomaceous member, Miocene, Maryland: Shattuck *et al.*, 2193.
Fairview formation, Ordovician, Ohio and Kentucky: Bassler, 156.
Fall Creek conglomerate lentil, Devonian, New York: Williams, 2583.
Farnham formation, Ordovician, Canada: Young, 2660.
Fayette clays, Tertiary, Texas: Ries, 2058.
Fayette sands, Tertiary, Texas: Fenneman, 859.
Fayetteville formation, Mississippian, Arkansas: Purdue, 1971.
Fayetteville formation, Mississippian, Indian Territory: Taff, 2332.
Fern Glen formation, Mississippian, Missouri: Weller, 2519.
Fern Glen (Kinderhook), Mississippian, Illinois: Fenneman, 860.
Fernando formation, Miocene-Pliocene-Pleistocene, California: Arnold and Anderson, 66.
Fernando formation, Pliocene, California: Arnold, 63; Eldridge and Arnold, 779.
Fernando formation, Tertiary, California: Arnold and Anderson, 67.
Fernie shale, Alberta: Dowling, 735.
Fernie shale, Jurassic, Alberta: Cairnes, 381; Dowling, 736.
Fickett series, Carboniferous (in part), Alaska: Brooks, 313.
Fish Creek sandstone, Carboniferous, Appalachian region: Stevenson, 2295.
Fish Creek sandstone, Carboniferous, Pennsylvania: Clapp, 476.
Fish Creek sandstone, Carboniferous, West Virginia: Grimsley, 1046.
Fishpot limestone, Carboniferous, Appalachian region: Stevenson, 2295.
Fishpot limestone, Carboniferous, Pennsylvania: Clapp, 475.
Flades clay, Silurian, Kentucky: Foerste, 883, 884.
Flathead quartzite, Cambrian, Montana: Emmons, 806; Rowe, 2090; Walcott, 2470.
Flatwoods clay, Eocene, Mississippi: Logan and Hand, 1609.
Flatwoods clay, Tertiary, Mississippi: Crider, 595.
Fleming clay, Tertiary, Louisiana: Veatch, 2436, 2437.
Florena member of Garrison formation, Carboniferous, Kansas: Beede and Rogers, 181.
Florence beds, Permian, Kansas: Wooster, 2636.
Florence flints, Permian, Kansas: Wooster, 2636.
Florissant formation, Tertiary (Eocene), Colorado: Henderson, 1127.
Flower-pot shales, Permian, Kansas: Wooster, 2636.
Fordham gneiss, pre-Cambrian, New York: Berkey, 207.
Fort Atkinson limestone, Ordovician, Iowa: Calvin, 388.
Fort Benton shales, Cretaceous, Iowa: Macbride, 1639.
Fort Pierre formation, Cretaceous, Montana: Rowe, 2090.
Fort Riley limestones, Permian, Kansas: Wooster, 2636.
Fort Scott limestone, Pennsylvanian, Kansas: Schrader and Haworth, 2144: Wooster, 2636.
Fort Smith formation, Carboniferous, Arkansas: Collier, 556.
Fort Union, Cretaceous, Montana: Brown, 325.
Fort Union, Tertiary, Wyoming: Veatch, 2439.
Fort Union formation, Cretaceous, Montana: Leonard, 1564.
Fort Union formation, Cretaceous, North Dakota: Leonard, 1563.
Fort Union formation, Tertiary, Wyoming: Veatch, 2440.
Fort Worth formation, Cretaceous, Arkansas: Veatch, 2436.
Fortymile series, Alaska: Brooks, 313.
Fortymile Creek formation, pre-Devonian, Alaska: Prindle, 1956.
Fountain formation, Carboniferous, Colorado: Finlay, 868.
Fox Hills formation, Cretaceous, Montana: Brown, 325; Leonard, 1564; Rowe, 2090.
Fox Hills formation, Cretaceous, Wyoming: Darton, 642; Fisher, 873.
Fox Hills member of Montana formation, Cretaceous, North Dakota: Leonard, 1563.
Fox Hills sandstone, Cretaceous, Colorado: Darton, 648.
Fox Hills sandstone, Cretaceous, North Dakota: Leonard, 1560.
Fox Hills sandstone, Cretaceous, Wyoming: Darton and O'Harra, 656.

Franciscan formation, Jurassic?, California: Arnold and Anderson, 66, 67.
Franciscan (Golden Gate) series, pre-Cretaceous, California: Crandall, 591.
Franklin limestone, Carboniferous, Appalachian region: Stevenson, 2295.
Freda sandstone, Cambrian, Michigan; Lane and Seaman, 1518.
Freeport group, Carboniferous, West Virginia: Grimsley, 1044.
Freeport limestone, Carboniferous, Pennsylvania: Butts, 368; Stevenson, 2294.
Freeport limestone, Carboniferous, West Virginia: Grimsley, 1046.
Freeport sandstone, Carboniferous, Pennsylvania: Butts, 368; Woolsey, 2634.
Freeport (Roaring Creek) sandstone, Carboniferous, West Virginia: Grimsley, 1046.
Fremont limestone, Ordovician, Colorado: Darton, 648.
Frio clays, Tertiary, Texas: Fenneman, 859; Ries, 2058.
Frontier formation, Cretaceous, Wyoming: Schultz, 2151; Veatch, 2440.
Fulda sandstone, Permian, Texas: Case, 443.
Fulton green shale, Carboniferous, West Virginia: Grimsley, 1046.
Fulton member, Ordovician, Ohio and Kentucky: Bassler, 156.
Furnaceville iron ore, Silurian, New York: Hartnagel, 1085.
Furnaceville iron ore formation, Silurian, New York: Clarke, 494.
Fuson formation, Cretaceous, Wyoming: Darton and O'Harra, 656.
Gakona group, Tertiary, Alaska: Brooks, 313.
Galena (Boone) beds, Mississippian, Kansas: Wooster, 2636.
Galena dolomite, Ordovician, upper Mississippi Valley: Bain, 99.
Galena limestone, Ordovician, Iowa: Calvin, 387, 388; Leonard, 1559; Savage, 2128.
Galena limestone, Ordovician, Wisconsin: Grant, 1017; Grant and Burchard, 1021.
Galena series, Ordovician, upper Mississippi Valley: Sardeson, 2122.
Galena stage, Ordovician, Iowa: Beyer and Williams, 234.
Galesburg shale, Pennsylvanian, Kansas: Schrader and Haworth, 2144; Wooster, 2636.
Galice formation, Jurassic, Oregon: Diller, 724.
Gallatin limestone, Cambrian, Montana: Rowe, 2090.
Gardiner clays, Pleistocene, New England: Fuller, 913.
Garnett limestone, Carboniferous, Kansas: Wooster, 2636.
Garrard, Ordovician, Kentucky: Miller, 1748.
Garrison formation, Carboniferous, Kansas: Beede and Rogers, 181.
Gasconade limestone, Cambro-Ordovician, Missouri: Shepard, 2194.
Gatun formation, Oligocene, Panama: Howe, 1244.
Genesee black shale, Devonian, New York: Luther, 1633, 1634.
Genesee member, Devonian, Maryland: Clark and Mathews, 488.
Genesee shale, Devonian, New York: Williams, 2583.
Genesee shale, Devonian, Pennsylvania: Butts, 367.
Geneva limestone, Devonian, Indiana: Stauffer, 2278.
Genundewah limestone, Devonian, New York: Luther, 1633, 1634.
Gering beds, Tertiary, Wyoming and Nebraska: Peterson, 1916.
Giants Range granite, Algonkian, Minnesota: Abbott, 1.
Gila conglomerate, Quaternary, Arizona: Lee, 1541.
Gilboy sandstone, Carboniferous, West Virginia: Grimsley, 1046.
Gilmore sandstone, Carboniferous, Appalachian region: Stevenson, 2295.
Gilmore sandstone, Carboniferous, Pennsylvania: Clapp, 476.
Gladeville sandstone, Carboniferous, Virginia: Stone, 2311.
Glastonbury granite-gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Gleneyrie formation, Carboniferous, Colorado: Finlay, 868.
Glen Park limestone, Mississippian, Missouri: Weller, 2519.
Goobic sands, Quaternary, Alaska: Brooks, 313.
Goodland limestone, Cretaceous, Arkansas: Veatch, 2436.
Goodnight formation, Tertiary, Texas: Gould, 986.
Goodrich quartzite, pre-Cambrian, Michigan: Lane and Seaman, 1518.
Goose Creek marl, Miocene, South Carolina: Sloan, 2218.
Gordon sandstone, Devonian, Pennsylvania: Woolsey, 2634.
Gosport greensand, Eocene, Alabama: Smith, 2229.
Gower formation, Silurian, Iowa: Calvin, 387; Savage, 2128.
Gower stage, Silurian, Iowa: Beyer and Williams, 234.
Grafton quartzite, Cambrian, Rhode Island: Emerson and Perry, 790.
Grampus gneiss, pre-Cambrian, New York: Cushing, 614.
Grand Gulf formation, Miocene, Mississippi: Logan, 1608.
Grand Gulf formation, Pliocene, Alabama: Smith, 2229.

Grand Gulf formation, Tertiary, Gulf region: Smith, 2226, 2228.
Grand Gulf formation, Tertiary, Mississippi: Crider, 595; Crider and Johnson, 599.
Grand Rapids, upper and lower, Carboniferous, Michigan: Cooper, 575.
Graneros shale, Cretaceous, Colorado: Darton, 648; Fisher, 869.
Graneros shale, Cretaceous, Nebraska: Condra, 570.
Graneros shale, Cretaceous, Wyoming: Darton and O'Harra, 656.
Gravina series, Cretaceous, Alaska: Brooks, 313.
Graydon sandstone, Pennsylvanian, Missouri: Shepard, 2194.
Great conglomerate, Cambrian, Michigan: Lane and Seaman, 1518.
Great Smoky conglomerate, Cambrian, North Carolina and Tennessee: Keith, 1352.
Greenbrier formation, Mississippian, Maryland: Clark and Mathews, 488.
Greenbrier limestone, Carboniferous, Pennsylvania: Clapp, 475.
Greenbrier limestone, Carboniferous, West Virginia: Grimsley, 1044.
Greenbrier limestone, Mississippian, Pennsylvania: Clapp, 477.
Greenbrier limestone, Mississippian, Virginia: Bassler, 158.
Greendale bed, Ordovician, Kentucky: Foerste, 884.
Greene formation, Carboniferous, Appalachian region: Stevenson, 2295.
Greene formation, Carboniferous, Pennsylvania: Clapp, 475, 476.
Greene formation, Carboniferous, Pennsylvania: Stone and Clapp, 2314.
Greene formation, Carboniferous, Pennsylvania, Ohio, and West Virginia: Griswold and Munn, 1048.
Greene formation, Carboniferous (Pennsylvanian), Pennsylvania: Clapp, 477.
Greenhorn formation, Cretaceous, Wyoming: Darton and O'Harra, 656.
Greenhorn limestone, Cretaceous, Colorado: Darton, 648; Fisher, 869.
Greenhorn limestone, Cretaceous, Nebraska; Condra, 570.
Green River, Tertiary, Wyoming: Veatch, 2439.
Green River formation, Tertiary, Wyoming: Schultz, 2151; Veatch, 2437.
Greer formation, Permian, Texas: Gould, 986, 987.
Grenville series, pre-Cambrian: Adams *et al.*, 13.
Grenville series, pre-Cambrian, New York: Berkey, 207; Cushing, 614.
Grenville series, pre-Cambrian, Ontario: Miller and Knight, 1759.
Greyson formation, Algonkian, Montana: Barrell, 149.
Greyson shales, Algonkian, Montana: Rowe, 2090.
Grimes sandstone, Devonian, New York: Luther, 1634.
Guadaloupan series, Carboniferous, New Mexico: Keyes, 1377.
Gulf series, Cretaceous, Arkansas: Veatch, 2436.
Gunflint formation, Algonkian, Minnesota: Abbott, 1.
Gunstock dike, New Hampshire: Pirsson and Washington, 1934.
Gunstock gneiss, New Hampshire: Pirsson and Washington, 1934.
Guye formation, Tertiary, Washington: Smith and Calkins, 2240.
Hackberry shales, Devonian, Iowa: Williams, 2588.
Hackberry shales, Permian, Kansas: Wooster, 2636.
Haddam granite-gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Hale formation, Pennsylvanian, Arkansas: Purdue, 1971.
Hamburg beds, Cretaceous, South Carolina: Sloan, 2217.
Hamburg clays, Cretaceous, South Carolina: Sloan, 2218.
Hamburg slate, pre-Cambrian, Wisconsin: Weidman, 2512.
Hamilton formation, Devonian, Pennsylvania: Butts, 367.
Hamilton member, Devonian, Maryland: Clark and Mathews, 488.
Hamilton shales, Devonian, New York: Grabau, 991.
Hamilton shale formation, Devonian, New York: Williams, 2583.
Hamilton shale, Devonian, West Virginia: Grimsley, 1044.
Hampshire formation, Devonian, Maryland: Clark and Mathews, 488.
Hampshire formation, Devonian, West Virginia: Grimsley, 1044.
Hampton clays, Pleistocene, South Carolina: Sloan, 2218.
Hampton shale, Cambrian, Tennessee: Keith, 1354.
Hance formation, Carboniferous, Kentucky: Ashley and Glenn, 77.
Hannibal formation, Mississippian, Missouri: Shepard, 2194.
Harding sandstone, Ordovician, Colorado: Darton, 648.
Harper beds, Permian, Kansas: Wooster, 2636.
Harpers formation, Cambrian, Maryland: Clark and Mathews, 488.
Harpers formation, Cambrian, Pennsylvania: Stose, 2318.
Harpers shale, Cambrian, West Virginia: Grimsley, 1044.
Harrison beds, Tertiary, Wyoming and Nebraska: Peterson, 1916.
Harrison diorite, Cambrian, New York: Berkey, 207.
Harrodsburgh limestone, Mississippian, Indiana: Blatchley, 246; Reagan, 1998.

Hartford limestone, Carboniferous, Kansas: Wooster, 2636.
Hartland (Hoosac) schist, Connecticut: Gregory, 1034.
Hartland schist, Connecticut: Gregory and Robinson, 1038.
Hartshorne sandstone, Carboniferous, Arkansas: Collier, 556.
Harvard conglomerate, Massachusetts: Mansfield, 1674.
Hastings phase of Grenville series, pre-Cambrian: Adams *et al.*, 13.
Hatch shale and flags, Devonian, New York: Luther, 1634.
Hatchetigbee formation, Eocene, Alabama: Smith, 2229.
Hawkins formation, pre-Tertiary, Washington: Smith and Calkins, 2240.
Hayes River beds, Alaska: Brooks, 313.
Hebron gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Helderberg formation, Devonian, Maryland: Clark and Mathews, 488.
Helderberg limestone, Silurian, West Virginia: Grimsley, 1044.
Helen formation, Canada: Bell, 189.
Helen iron formation, Ontario: Coleman, 541; Moore, 1770.
Helena formation, Algonkian, Montana: Walcott, 2470.
Helena limestone, Algonkian, Montana: Barrell, 149.
Hell Creek beds, Cretaceous, Montana: Brown, 325.
Henderson granite, Archean, North Carolina and South Carolina: Keith, 1353.
Henrietta limestone, Pennsylvanian, Missouri: Shepard, 2194.
Henson tuff, Colorado: Cross *et al.*, 607.
Hermosa formation, Carboniferous (Pennsylvanian), Colorado: Cross *et al.*, 607.
Herod gravels, Pleistocene, New England: Fuller, 913.
Hertha limestone, Carboniferous, Kansas: Beede and Rogers, 181; Wooster, 2636.
Hesse quartzite, Cambrian, Tennessee: Keith, 1354.
Highbridge, Ordovician, Kentucky: Miller, 1748.
High Falls shale, Silurian, New York: Grabau, 991; Hartnagel, 1084.
High Point sandstone, Devonian, New York: Luther, 1634.
High Point sandstones, New York: Jones, 1318.
Hignite formation, Carboniferous, Kentucky: Ashley and Glenn, 77.
Hilliard formation, Cretaceous, Wyoming: Schultz, 2151.
Hiwassee slate, Cambrian, North Carolina: Keith, 1352.
Hiwassee slate, Cambrian, Tennessee: Keith, 1354.
Holston formation, Ordovician, Virginia: Bassler, 158.
Homewood sandstone, Carboniferous, Pennsylvania: Butts, 368.
Homewood sandstone, Carboniferous, Pennsylvania, Ohio, and West Virginia: Griswold and Munn, 1048.
Honaker limestone, Cambrian, Tennessee: Keith, 1354.
Honaker limestone, Cambrian, Virginia: Bassler, 158.
Hoosac schist, Connecticut: Gregory, 1034.
Hopkinton formation, Silurian, Iowa: Calvin, 387; Norton, 1805; Savage, 2128.
Hopkinton stage, Silurian, Iowa: Beyer and Williams, 234.
Hornerstown, Cretaceous, New Jersey: Clark, 483.
Hornerstown marl, Cretaceous, New Jersey: Weller, 2520.
Hornsboro sandstone, Jura-Triassic, South Carolina: Sloan, 2218.
Horsefly gravels, Tertiary, Yukon Territory: Brooks, 313.
Hosselkus limestone, Triassic, California: Diller, 721.
Howard limestone, Carboniferous, Kansas: Wooster, 2636.
Howson andesite, Tertiary, Washington: Smith and Calkins, 2240.
Hudson River slates, Ordovician, New York: Berkey, 207.
Hudson schist, Cambro-Ordovician, Connecticut: Hobbs, 1185.
Hueco limestone, Carboniferous, New Mexico: Keyes, 1377.
Humphrey shales, Carboniferous, Kansas: Wooster, 2636.
Hunker series, Yukon Territory: Brooks, 313.
Huron group, Mississippian, Indiana: Blatchley, 246.
Huronian, lower, series, pre-Cambrian, Ontario: Silver, 2212.
Huronian sediments, pre-Cambrian, Ontario: Coleman, 539.
Idaho Springs formation, pre-Cambrian, Colorado: Ball, 118.
Ignacio quartzite, Cambrian, Colorado: Cross *et al.*, 607.
Illinoian, Quaternary, Iowa: Calvin, 387.
Independence limestone, Carboniferous, Kansas: Wooster, 2636.
Independence sub-stage, Devonian, Iowa: Norton, 1805.
Indian Fields formation, Silurian, Kentucky: Foerste, 883, 884.
Indian River series, Yukon Terrltory: Brooks, 313.
Inwood limestone, pre-Cambrian, New York: Berkey, 207.
Iola limestone, Pennsylvanian, Kansas: Beede and Rogers, 181; Schrader and Haworth, 2144.
Iola (Earlton) limestone, Carboniferous, Kansas: Wooster, 2636.
Ione formation, Tertiary, California: Diller, 721.

Iowan drift, Pleistocene, Iowa: Arey, 53; Calvin, 387, 388; Leonard, 1559; Macbride, 1639; Norton, 1805; Savage, 2128; Williams, 2588.
Irasburg conglomerate, Ordovician, Vermont: Richardson, 2037.
Irondequoit limestone, Silurian, New York: Clarke, 494; Hartnagel, 1085.
Iron Mountain porphyry, Archean, Missouri: Shepard, 2194.
Ironwood, Michigan: Gordon and Lane, 985.
Irvine formation, Tertiary, Kentucky: Foerste, 883, 884.
Isle La Motte sandstone, Ordovician, Vermont: Seely, 2164.
Islesboro formation, Cambrian, Maine: Smith *et al.*, 2241.
Ithaca formation, Devonian, New York: Grabau, 991.
Ithaca shale member, Devonian, New York: Williams, 2583.
Izard limestone, Ordovician, Arkansas: Purdue, 1970.
Jackson formation, Eocene, Mississippi: Logan, 1608.
Jackson formation, Tertiary, Louisiana and Arkansas: Veatch, 2436, 2437.
Jackson formation, Tertiary, Mississippi: Crider, 595, 598; Crider and Johnson, 599.
Jackson limestone, Carboniferous, Appalachian region: Stevenson, 2295.
Jackson stage, Eocene, Louisiana: Harris, 1079.
Jacob sand, Pleistocene, New England: Fuller, 913.
Jacobsville sandstone, Cambrian, Michigan: Lane and Seaman, 1518.
Jameco, Pleistocene, New England: Fuller, 913.
Jameco gravel, Quaternary, New York: Veatch, 2434.
Jefferson limestone, Devono-Silurian, Montana: Emmons, 806.
Jefferson City limestone, Cambro-Ordovician, Missouri: Shepard, 2194.
Jeffersonville limestone, Devonian, Indiana: Blatchley, 246; Stauffer, 2278.
Jennings formation, Devonian, Maryland: Clark and Mathews, 488.
Jennings formation, Devonian, West Virginia: Grimsley, 1044.
Jerseyan, Quaternary, Iowa: Norton, 1805.
Jessamine series, Ordovician, Kentucky: Foerste, 884.
Joachim limestone, Cambro-Ordovician, Missouri: Shepard, 2194.
Joachim limestone, Ordovician, Illinois: Weller, 2523.
Johnston cement limestone, Carboniferous, Pennsylvania: Stevenson, 2294.
Jollytown limestone, Carboniferous, Appalachian region: Stevenson, 2295.
Jollytown limestone, Carboniferous, Pennsylvania: Clapp, 475.
Jordan formation, Cambrian, Iowa: Calvin, 387, 388.
Jordan sandstone, Cambrian, Iowa: Beyer and Williams, 234.
Judith River beds, Cretaceous, Alberta: Cairnes, 381.
Judith River formation, Cretaceous, Canada: Dowling, 735.
Junction City quartzite, pre-Cambrian, Wisconsin: Weidman, 2512.
Juniata formation, Silurian, Maryland: Clark and Mathews, 488.
Kachess rhyolite, Tertiary, Washington: Smith and Calkins, 2240.
Kanab sandstone, Utah: Lee, 1544.
Kanawha series, Carboniferous, West Virginia: Grimsley, 1044.
Kansan drift, Quaternary, Iowa: Arey, 53; Calvin, 387, 388; Leonard, 1559; Macbride, 1639; Savage, 2128; Williams, 2588.
Kansan (?) deposits, Quaternary, Pennsylvania: Woolsey, 2634.
Kanwaka shales, Carboniferous, Kansas: Wooster, 2636.
Kasaan greenstone, Cretaceous, Alaska: Brooks, 313.
Katalla formation, Tertiary, Alaska: Martin, 1680.
Kearsarge conglomerate, Michigan: Lane, 1507.
Kearsarge conglomerate, Algonkian, Michigan: Lane, 1509.
Keechelus andesitic series, Tertiary, Washington: Smith and Calkins, 2240.
Keewatin, pre-Cambrian, Ontario: Silver, 2212.
Keeweenawan, Algonkian, Michigan: Gordon and Lane, 985.
Kelly formation, Carboniferous, New Mexico: Gordon, 982.
Kelly limestone, Mississippian, New Mexico: Gordon, 981.
Kenai formation, Tertiary, Alaska: Moffit, 1762; Paige and Knopf, 1860; Prindle, 1956; Stone, 2308.
Kenai series, Tertiary, Alaska: Brooks, 313.
Kennett formation, Devonian, California: Diller, 721.
Kennicott formation, Jura-Cretaceous, Alaska: Brooks, 313.
Keokuk limestone, Mississippian, Illinois: Weller, 2523.
Keokuk limestone, Mississippian, Missouri: Shepard, 2194.
Keokuk limestone and shale, Mississippian, Iowa: Beyer and Williams, 234.
Kessler limestone lentil, Pennsylvanian, Arkansas: Purdue, 1971.
Ketchikan series, Carboniferous, Alaska: Kindle, 1400.
Ketchikan series, Triassic and Carboniferous, Alaska: Brooks, 313.
Keweenawan, pre-Cambrian, Michigan: Lane and Seaman, 1518.

Keweenawan, pre-Cambrian, Ontario: Silver, 2212.
Keweenawan series, Ontario: Moore, 1770.
Kiddville layer, Devonian, Kentucky: Foerste, 884.
Kiger beds, Permian, Kansas: Wooster, 2636.
Kigluaik series, Alaska: Brooks, 313; Moffit, 1764.
Kimmswick limestone, Ordovician, Illinois: Weller, 2522, 2523.
Kimmswick limestone, Ordovician, Missouri: Weller, 2519.
Kinderhook, Mississippian, Iowa: Beyer and Williams, 234.
Kinderhook formation, Carboniferous, Iowa: Calvin, 387.
Kinderhook group, Mississippian, Illinois: Bowman and Reeds, 277.
Kinderhook shale, Mississippian, Illinois: Weller, 2523.
Kingsbury conglomerate, Cretaceous, Wyoming: Darton, 644–647.
King's Creek silex, Oligocene, South Carolina: Sloan, 2218.
Kingston group, Canada: Ells, 784.
Kitchener quartzite, Idaho and Montana: Daly, 631.
Kittanning group, Carboniferous, West Virginia: Grimsley, 1044.
Kittanning sandstone, Carboniferous, Pennsylvania: Butts, 368.
Klondike series, Yukon Territory: Brooks, 313.
Knife slates, Algonkian, Minnesota: Abbott, 1.
Knight beds, Tertiary, Wyoming: Veatch, 2439.
Knight formation, Tertiary, Wyoming: Schultz, 2151.
Knob Lick granite, Archean, Missouri: Shepard, 2194.
Knobstone, Mississippian, Indiana: Reagan, 1998.
Knox dolomite, Cambro-Ordovician, Virginia: Bassler, 158.
Knox dolomite, Ordovician, Alabama: Butts, 370; Smith, 2229.
Knox dolomite, Ordovician, Georgia: Watson, 2483.
Knox dolomite, Ordovician, Tennessee: Keith, 1354.
Knox limestone, Cambrian and Ordovician, Maryland: Clark and Mathews, 488.
Knox limestone, Cambro-Ordovician, Pennsylvania: Stose, 2318.
Knoxville beds, Cretaceous, California: Crandall, 590.
Knoxville formation, Cretaceous, California: Arnold and Anderson, 66, 67.
Kona dolomite, pre-Cambrian, Michigan: Lane and Seaman, 1518.
Kootanie coal measures, Cretaceous, Alberta: Dowling, 736.
Kootanie formation, Cretaceous, Alberta: Cairnes, 381; Dowling, 735.
Kootanie series, Cretaceous, Montana and Alberta: Knowlton, 1418.
Kootenai formation, Cretaceous, Montana: Rowe, 2090.
Koyukuk series, Cretaceous, Alaska: Brooks, 313.
Kruger schists, Paleozoic, Washington and British Columbia: Daly, 632.
Kushtaka formation, Tertiary, Alaska: Martin, 1680.
Kuzitrin formation, Alaska: Brooks, 313; Moffit, 1764.
Labette shale, Pennsylvanian, Kansas. Schrader and Haworth, 2144; Wooster, 2636.
Ladore shale, Carboniferous, Kansas: Wooster, 2636.
Ladore-Dudley shale, Pennsylvanian, Kansas: Schrader and Haworth, 2144.
Ladronesian series, Carboniferous, New Mexico: Keyes, 1377, 1382.
Lafayette formation, Gulf region: Smith, 2228.
Lafayette formation, Mississippi: Logan and Hand, 1609.
Lafayette formation, Pliocene, Alabama: Smith, 2229.
Lafayette formation, Pliocene, Maryland: Clark and Mathews, 488; Shattuck, 2184, 2191.
Lafayette formation, Pliocene?, Maryland: Shattuck *et al.*, 2193.
Lafayette formation, Quaternary, Mississippi: Brown, 326; Crider, 595; Logan, 1608.
Lafayette formation, Tertiary, Georgia: Harper, 1077.
Lafayette formation, Tertiary, Gulf region: Smith, 2226.
La Fayette formation, Tertiary, Illinois: Purdy and DeWolf, 1973.
Lafayette formation, Tertiary, Louisiana and Arkansas: Veatch, 2436, 2437.
Lafayette formation, Tertiary, Maryland and Delaware: Miller, 1749.
Lafayette formation, Tertiary, Mississippi: Crider and Johnson, 599.
Lafayette formation, Tertiary, South Carolina: Pugh, 1963.
Lafayette formation, Tertiary, Tennessee, Kentucky, and Illinois: Glenn, 971.
Lafayette formation, Tertiary, Texas: Ries, 2058.
Lafayette formation, Tertiary, Virginia: Clark and Miller, 489.
Lafayette gravel, Tertiary, Illinois: Weller, 2523.
Lafayette gravel, Tertiary, Missouri: Shepard, 2194.
Lafayette sands, Tertiary, Texas: Fenneman, 859.
Lagrange division, Mississippi: Logan and Hand, 1609.
Lagrange formation, Tertiary, Illinois: Purdy and DeWolf, 1973.

Lagrange formation, Tertiary, Missouri: Shepard, 2194.
Lagrange formation, Tertiary, Tennessee, Kentucky and Illinois: Glenn, 971.
Lake Shore trap, Algonkian, Michigan: Gordon and Lane, 985.
Lake Shore traps, Cambrian, Michigan: Lane and Seaman, 1518.
Lake Superior sandstone, Cambrian, Michigan: Lane and Seaman, 1518.
Lake Valley formation, Carboniferous, New Mexico: Keyes, 1377.
Lake Valley limestone, Mississippian, New Mexico: Gordon, 981.
Lakota sandstone, Cretaceous, Wyoming: Darton and O'Harra, 656.
La Motte sandstone, Cambrian, Missouri: Shepard, 2194.
Lane shales, Carboniferous, Kansas: Beede and Rogers, 181; Wooster, 2636.
Lantern Hill quartz rock, Connecticut: Gregory, 1034.
La Plata formation, Jurassic, Colorado: Cross, 604.
La Plata sandstone, Jurassic, Colorado: Cross *et al.*, 607.
Laramie, Wyoming: Veatch, 2439.
Laramie formation, Cretaceous, Colorado: Darton, 648; Fenneman and Gale, 863.
Laramie formation, Cretaceous, Colorado and New Mexico: Shaler, 2176.
Laramie formation, Cretaceous, North Dakota: Leonard, 1563.
Laramie formation, Cretaceous, North Dakota and Montana: Leonard, 1560.
Laramie formation, Cretaceous, Wyoming: Darton, 642; Fisher, 873; Rowe, 2090; Veatch, 2437.
Laramie formation, Cretaceous and Tertiary, Wyoming: Veatch, 2440.
Lauderdale chert, Mississippian, Alabama: Smith, 2229.
Laurentian, pre-Cambrian: Adams *et al.*, 13.
Lawrence beds, Carboniferous, Kansas: Wooster, 2636.
Le Claire substage, Silurian, Iowa: Beyer and Williams, 234.
Lecompton beds, Carboniferous, Kansas: Wooster, 2636.
Lee conglomerate, Carboniferous, Virginia: Stone, 2311.
Lee formation, Carboniferous, Kentucky: Ashley and Glenn, 77.
Lenoir limestone, Ordovician, Virginia: Bassler, 158.
Le Roy shales, Carboniferous, Kansas: Wooster, 2636.
Lewis formation, Cretaceous, Wyoming: Veatch, 2440.
Lewis shale, Cretaceous, Colorado: Fenneman and Gale, 863.
Lewis shale, Cretaceous, Colorado and New Mexico: Shaler, 2176.
Lewiston limestone, Ordovician, Virginia: Bassler, 158.
Lewiston limestone, Silurian, West Virginia: Grimsley, 1044.
Lewiston ("Helderberg"), Virginia: Eckel, 765.
Lexington, Ordovician, Kentucky: Miller, 1748.
Lime Creek shales, Devonian, Iowa: Beyer and Williams, 234; Calvin, 387; Williams, 2588.
Linietta clay, Mississippian, Kentucky: Foerste, 883.
Linville metadiabase, Algonkian?, North Carolina: Keith, 1354.
Lisbon beds, Tertiary, Mississippi: Crider, 595; Crider and Johnson, 599.
Lisbon formation, Eocene, Alabama: Smith, 2229.
Lisburne series, Carboniferous, Alaska: Brooks, 313; Collier, 552.
Litchfield norite, Connecticut: Gregory, 1034.
Livingston formation, Cretaceous, Wyoming: Rowe, 2090.
Llano Estacado formation, Pliocene, New Mexico: Keyes, 1388.
Llano Estacado sands, Pliocene, New Mexico: Keyes, 1390.
Lockport dolomite, Silurian, New York: Hartnagel, 1085.
Lodore shales, Cambrian, Utah: Weeks, 2506.
Logan formation, Carboniferous, Ohio: Carney, 427.
Logan sills, Ontario: Silver, 2212.
Logana, Ordovician, Kentucky: Miller, 1748.
Lone Mountain limestone, Silurian, Nevada and California: Ball, 120.
Longwood shale, Silurian, New York: Hartnagel, 1084.
Lorraine sandstone, Ordovician, New York: Grabau, 991.
Loudon formation, Cambrian, Maryland: Clark and Mathews, 488.
Louisiana limestone, Mississippian, Illinois: Weller, 2523.
Louisiana limestone, Mississippian, Missouri: Shepard, 2194.
Loup Fork formation, Tertiary, Texas: Gould, 986.
Lowerre quartzite, pre-Cambrian, New York: Berkey, 207.
Lucas dolomite, Devonian, Michigan: Lane, 1516.
Ludlowville shale, Devonian, New York: Luther, 1633.
Lulbegrud clay, Silurian, Kentucky: Foerste, 883, 884.
Lunenburg schist, pre-Cambrian, Vermont: Richardson, 2037.
Lyme granite-gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
McAlester group, Carboniferous, Arkansas: Collier, 556.
McCloud limestone, Carboniferous, California: Diller, 721.

M'Elmo formation, Jurassic, Colorado: Cross, 604; Cross *et al.*, 607.
McKim graywacke, pre-Cambrian, Ontario: Coleman, 539.
McMicken member, Ordovician, Ohio and Kentucky: Bassler, 156.
McMillan formation, Ordovician, Ohio: Bassler, 156.
Maderan limestone, Carboniferous, New Mexico: Gordon, 982.
Maderan series, Carboniferous, New Mexico: Keyes, 1377.
Madison limestone, Carboniferous, Montana: Emmons, 806.
Madison limestone, Carboniferous, Wyoming: Darton, 642, 644–647; Fisher, 873.
Madison formation, Mississippian, Montana: Rowe, 2090.
Magdalena group, Carboniferous, New Mexico: Gordon, 982.
Magnesian, lower, limestone, Ordovician, Illinois: Weller, 2517, 2523, 2524.
Magnesian, lower, limestone, Ordovician, Iowa: Leonard, 1559.
Magnesian, lower, Ordovician, Mississippi Valley: Davis, 663.
Magnesian, lower, limestone, Ordovician, Wisconsin: Grant, 1017.
Magothy formation, Cretaceons, Maryland: Clark and Mathews, 488; Shattuck *et al.*, 2193.
Magothy formation, Cretaceous, Maryland and Delaware: Miller, 1749.
Magothy formation, Cretaceous, New Jersey: Berry, 214; Weller, 2520.
Mahoning group, Carboniferous, West Virginia: Grimsley, 1044.
Mahoning limestone, Carboniferous, Pennsylvania: Stevenson, 2294.
Mahoning sandstone, Carboniferous, Pennsylvania: Butts, 368; Woolsey, 2634.
Mahoning sandstone, Carboniferous, Pennsylvania, Ohio, and West Virginia: Griswold and Munn, 1048.
Mahoning sandstone, Carboniferous, West Virginia: Grimsley, 1046.
Mamacoke gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Manasquan marl, Cretaceous, New Jersey: Weller, 2520.
Manastash formation, Tertiary, Washington: Smith and Calkins, 2240.
Mancos shale, Cretaceous: Fenneman and Gale, 863.
Mancos shale, Cretaceous, Colorado: Cross *et al.*, 607; Taff, 2336.
Mancos shale, Cretaceous, Colorado and New Mexico: Shaler, 2176.
Manhattan schist, pre-Cambrian, New York: Berkey, 207.
Manitou limestone, Ordovician, Colorado: Darton, 648.
Mankomen group, Permian, Alaska: Brooks, 313.
Manlius limestone, Silurian, New York: Grabau, 991; Hartnagel, 1084; Prosser, 1961.
Manlius member, Silurian, Maryland: Clark and Mathews, 488.
Mannetto, Pleistocene, New England: Fuller, 913.
Mannetto gravel, Quaternary, New York: Veatch, 2434.
Mansfield sandstone, Carboniferous, Illinois: Blatchley, 245.
Manzanan series, Carboniferous, New Mexico: Keyes, 1377.
Manzano group, Carboniferous, New Mexico: Gordon, 982.
Maquoketa formation, Ordovician, Iowa: Calvin, 387, 388; Leonard, 1559; Norton, 1805; Savage, 2128.
Maquoketa shale, Ordovician, Illinois: Weller, 2517, 2522, 2524.
Maquoketa shale, Ordovician, Iowa: Grant and Burchard, 1021.
Maquoketa shale, Ordovician, upper Mississippi Valley: Bain, 99.
Maquoketa (Hudson River) shale, Ordovician, Mississippi Valley: Davis, 663.
Maquoketa (Hudson River) limestone, Ordovician, Wisconsin: Grant, 1017.
Maquoketa stage, Ordovician, Iowa: Beyer and Williams, 234.
Marathon City conglomerate, pre-Cambrian, Wisconsin: Weidman, 2512.
Marblehead member of Columbus formation, Devonian: Swartz, 2329.
Marcellus shale, Devonian, Michigan: Cooper, 575.
Marcellus shale, Devonian, New York: Grabau, 991; Luther, 1633; Williams, 2583.
Marcellus shale, Devonian, Pennsylvania: Butts, 367.
Mareniscan, pre-Cambrian, Michigan: Lane and Seaman, 1518.
Marietta sandstones, Carboniferous, West Virginia: Grimsley, 1046.
Marion beds, Permian, Kansas: Wooster, 2636.
Mariposa slates, California: Reid, 2018.
Marks Head marl, Miocene, South Carolina: Sloan, 2218.
Marlboro formation, Cambrian, Rhode Island: Emerson and Perry, 790.
Marlbrook formation, Cretaceous, Arkansas: Veatch, 2436.
Maromas granite-gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Marsh formation, Algonkian, Montana: Walcott, 2470.
Marsh shale, Algonkian, Montana: Barrell, 149.
Marshall formation, Carboniferous, Michigan: Cooper, 575.
Marshall sandstone, Mississippian, Michigan: Lane, 1516.
Marshall Hill graywacke, pre-Cambrian, Wisconsin: Weidman, 2512.
Marshalltown clay-marl, Cretaceous, New Jersey: Weller, 2520.
Martinez formation, Tertiary, California: Arnold, 57.

Martinsburg formation, Ordovician, Maryland: Clark and Mathews, 488.
Martinsburg group, Ordovician, Pennsylvania: Stose, 2318.
Martinsburg shale, Silurian, West Virginia: Grimsley, 1044.
Martinsburg shale group and limestones, Ordovician, Virginia: Bassler, 158.
Maryville limestone, Cambrian, Virginia: Bassler, 158.
Mascarene series, Devonian, Canada: Ells, 784.
Mason City dolomite, Devonian, Iowa: Williams, 2588.
Massanutten sandstone group, Ordovician, Virginia: Bassler, 158.
Matanuska series, Alaska: Martin, 1682.
Matawan formation, Cretaceous, Maryland: Clark and Mathews, 488; Shattuck *et al.*, 2193.
Matawan formation, Cretaceous, Maryland and Delaware: Miller, 1749.
Matawan, Cretaceous, New York: Veatch, 2434.
Matfield shales and limestones, Permian, Kansas: Wooster, 2636.
Mauch Chunk formation, Carboniferous, Pennsylvania: Butts, 368; Clapp, 475, 477; Woolsey, 2634.
Mauch Chunk formation, Lower Carboniferous, Pennsylvania: Barrell, 150.
Mauch Chunk formation, Mississippian, Maryland: Clark and Mathews, 488.
Mauch Chunk shales, Carboniferous, West Virginia: Grimsley, 1044.
Maxville or Bayport formation, Carboniferous, Michigan: Cooper, 575.
Meagher limestone, Cambrian, Montana: Emmons, 806.
Medicine Lodge beds, Permian, Kansas: Wooster, 2636.
Medicine Lodge gypsum, Permian, Kansas: Wooster, 2636.
Medina formation, Silurian, New York: Hartnagel, 1085.
Medina formation, Silurian, West Virginia: Grimsley, 1044.
Memphremagog slate, Vermont: Richardson, 2037.
Mentasta schists, Alaska: Brooks, 313.
Menteth limestone, Devonian, New York: Luther, 1634.
Meramec limestones, Mississippian, Illinois: Bowman and Reeds, 277.
Merced formation, Tertiary, California: Prindle, 1956.
Merced series, Pliocene, California: Crandall, 591.
Mercer shale, Carboniferous, Pennsylvania: Butts, 368.
Mercer group, Carboniferous, West Virginia: Grimsley, 1044.
Merchantville clay-marl, Cretaceous, New Jersey: Weller, 2520.
Mesaverde formation, Cretaceous, Colorado: Cross *et al.*, 607; Fenneman and Gale, 863; Taff, 2336.
Mesaverde formation, Cretaceous, Colorado and New Mexico: Shaler, 2176.
Mesaverde formation, Cretaceous, Wyoming: Veatch, 2440.
Mesnard quartzite, pre-Cambrian, Michigan: Lane and Seaman, 1518.
Michigamme slate, pre-Cambrian, Michigan: Gordon and Lane, 985; Lane and Seaman, 1518.
Michigan series, Mississippian, Michigan: Lane, 1516.
Michipicoten schists, Ontario: Moore, 1770.
Middendorf beds, Cretaceous, South Carolina: Sloan, 2217, 2218.
Middlesex black shale, Devonian, New York: Luther, 1633.
Middlesex shales, Devonian, New York: Luther, 1634.
Middletown gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Midway formation, Tertiary, Arkansas and Louisiana: Veatch, 2436, 2437.
Midway group, Eocene, Alabama: Smith, 2229.
Midway group, Tertiary, Mississippi: Crider, 595; Crider and Johnson, 599.
Midway stage, Eocene, Mississippi: Logan, 1608.
Milford chlorite schist, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Milford granite, post-Cambrian, pre-Carboniferous, Rhode Island: Emerson and Perry, 790.
Million, Ordovician, Kentucky: Miller, 1748.
Millsap formation, Carboniferous, Texas: Ries, 2058.
Millsap limestone, Carboniferous, Colorado: Darton, 648.
Milwaukee formation, Devonian, Wisconsin: Alden, 23.
Mimbres limestone, Siluro-Ordovician, New Mexico: Gordon, 981.
Mingo formation, Carboniferous, Kentucky: Ashley and Glenn, 77.
Minneapolis limestone, Ordovician, Minnesota: Sardeson, 2122.
Minnesota conglomerate, Algonkian, Michigan: Lane, 1509.
Mio-Huronian, pre-Cambrian, Michigan: Lane and Seaman, 1518.
Missouri group, Pennsylvanian, Missouri: Shepard, 2194.
Missouri stage, Pennsylvanian, Iowa: Beyer and Williams, 234.
Missourian formation, Carboniferous, Iowa: Calvin, 387.
Mitchell limestone, Mississippian, Indiana: Blatchley, 246; Reagan, 1998.
Moccasin limestone, Ordovician, Virginia: Bassler, 158.
Modelo formation, Miocene, California: Eldridge and Arnold, 779.
Modin formation, Jurassic, California: Diller, 721.
Mooncopie formation, Carboniferous, New Mexico: Keyes, 1377.

Moencopie formation, Carboniferous, Utah: Lee, 1544.
Moencopie shales, Permian, Utah: Huntington, 1257.
Molas formation, Carboniferous (Pennsylvanian), Colorado: Cross *et al.*, 607.
Monarch formation, Devonian and Silurian, Montana: Rowe, 2090.
Monmouth formation, Cretaceous, Maryland: Clark and Mathews, 488; Shattuck *et al.*, 2193.
Monmouth formation, Cretaceous, Maryland and Delaware: Miller, 1749.
Monongahela formation, Carboniferous, Appalachian region: Stevenson, 2295.
Monongahela formation, Carboniferous, Pennsylvania: Clapp, 475–477; Stone and Clapp, 2314; Woolsey, 2634.
Monongahela formation, Carboniferous, Pennsylvania, Ohio, and West Virginia: Griswold and Munn, 1048.
Monongahela formation, Pennsylvanian, Maryland: Clark and Mathews, 488.
Monongahela series, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Monroe beds, North Carolina: Graton, 1025.
Monroe limestone, Devonian, Michigan: Lane, 1516.
Monroe Creek beds, Tertiary, Wyoming and Nebraska: Peterson, 1916.
Monson granite gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Montalto quartzite member of Harpers formation, Cambrian, Pennsylvania: Stose, 2318.
Montana formation, Cretaceous, Canada: Dowling, 735.
Montana formation, Cretaceous, Montana: Darton, 652.
Montana formation, Cretaceous, North Dakota: Leonard, 1563.
Montana formation, Cretaceous, Wyoming: Veatch, 2437.
Montara granite, California: Crandall, 591.
Montauk drift, Pleistocene, New England: Fuller, 913.
Monterey sandstone, Devonian, West Virginia: Grimsley, 1044.
Monterey shale, Miocene, California: Arnold, 63; Arnold and Anderson, 66, 67.
Monterey shale, Tertiary, California: Prindle, 1956.
Montosa formation, Carboniferous, New Mexico: Keyes, 1377.
Montpelier slate, Vermont: Richardson, 2037.
Montrose cherts, Mississippian, Iowa: Beyer and Williams, 234.
Monument Creek formation, Tertiary, Colorado: Darton, 648.
Moose Hide group, Yukon Territory: Brooks, 313.
Morgantown sandstone, Carboniferous, Pennsylvania: Stevenson, 2294; Woolsey, 2634.
Morgantown sandstone, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Morrison formation, Cretaceous, Colorado: Darton, 648.
Morrison formation, Cretaceous, Wyoming: Darton, 642, 644–647; Fisher, 873.
Morrison shale, Cretaceous, Wyoming: Darton and O'Harra, 656.
Morrow formation, Carboniferous, Indian Territory: Taff, 2332.
Morrow group, Pennsylvanian, Arkansas: Purdue, 1971.
Mosca formation, Carboniferous, New Mexico: Keyes, 1377.
Moscow shale, Devonian, New York: Luther, 1633, 1634.
Mosinee conglomerate, pre-Cambrian, Wisconsin: Weidman, 2512.
Mound Valley limestone, Pennsylvanian, Kansas: Beede and Rogers, 181; Schrader and Haworth, 2144; Wooster, 2636.
Mount Bohemia conglomerate, Michigan: Lane, 1507, 1509.
Mount Hope marl, Eocene, South Carolina: Sloan, 2218.
Mount Laurel formation, Cretaceous, New Jersey: Weller, 2520.
Mount Selman beds, Tertiary, Texas: Fenneman, 859.
Mount Stuart granodiorite, pre-Tertiary, Washington: Smith and Calkins, 2240.
Mowry formation, Cretaceous, Wyoming: Veatch, 2440.
Mowry member, Cretaceous, Wyoming: Darton, 645; Darton and O'Harra, 656.
Moyie argillite, Idaho and Montana: Daly, 631.
Munising sandstone, Cambrian, Michigan: Lane and Seaman, 1518.
Murphy marble, Cambrian, North Carolina: Keith, 1352.
Murray slate, Cambrian, Tennessee: Keith, 1354.
Myrtle formation, Cretaceous, Oregon: Diller, 724.
Nabesna limestone, Carboniferous, Alaska: Brooks, 313.
Nacatoch sand, Cretaceous, Arkansas: Veatch, 2436.
Naches formation, Tertiary, Washington: Smith and Calkins, 2240.
Nacimientan series, Eocene, New Mexico: Keyes, 1390.
Naese sandstone member, Carboniferous, Kentucky: Ashley and Glenn, 77.
Naheola formation, Eocene, Alabama: Smith, 2229.
Namacoke gneiss, Connecticut: Gregory and Robinson, 1038.
Nanafalia formation, Eocene, Alabama: Smith, 2228, 2229.
Nanaimo group, Cretaceous, British Columbia: Brooks, 313.
Nanjemoy formation, Eocene, Maryland: Clark and Mathews, 488; Shattuck, 2188; Shattuck *et al.*, 2193.
Nanjemoy formation, Tertiary, Virginia: Clark and Miller, 489.

Nantahala slate, Cambrian, North Carolina: Keith, 1352.
Napoleon formation, Carboniferous, Michigan: Cooper, 575.
Narragansett Basin series, Massachusetts: Mansfield, 1674.
Natchez formation, Quaternary, Mississippi: Logan, 1608.
Navarro marls, Cretaceous, Texas: Ries, 2058.
Navesink formation, Cretaceous, New Jersey: Weller, 2520.
Nebo quartzite, Cambrian, Tennessee: Keith, 1354.
Needle Mountains group, Algonkian, Colorado: Cross *et al.*, 607.
Negaunee formation, pre-Cambrian, Michigan: Lane and Seaman, 1518.
Neihart quartzite, Algonkian, Montana: Rowe, 2090.
Neo-Huronian, pre-Cambrian, Michigan: Lane and Seaman, 1518.
Neosho member of Garrison formation, Carboniferous, Kansas: Beede and Rogers, 181.
Neva limestone, Carboniferous, Kansas: Beede and Rogers, 181; Wooster, 2636.
Nevada limestone, Devonian, Nevada: Lawson, 1526.
New Albany or Genesee shale, Devonian, Indiana: Blatchley, 246.
Newark formation, Triassic, Maryland: Clark and Mathews, 488.
Newark system, Triassic, New Jersey: Lewis, 1580.
Newland limestone, Algonkian, Montana: Rowe, 2090.
New London granite-gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Newman limestone, Carboniferous, Virginia: Bassler, 158.
New Providence shales, Mississippian, Indiana: Reagan, 1998.
New Richmond formation, Ordovician, Iowa: Calvin, 387, 388.
New Richmond formation, Ordovician, upper Mississippi Valley: Bain, 99.
New Richmond sandstone, Ordovician, Iowa: Beyer and Williams, 234.
New Scotland limestone, Devonian, New York: Hartnagel, 1084.
New Scotland beds, Devonian, Mississippi: Crider, 595.
New Scotland beds, Devonian, New York: Grabau, 991.
New Scotland member, Devonian, Maryland: Clark and Mathews, 488.
Niagara dolomite, Silurian, upper Mississippi Valley: Bain, 99.
Niagara limestone, Silurian, Indiana: Blatchley, 246.
Niagara limestone Silurian, Iowa: Beyer and Williams, 234; Calvin, 388; Grant and Burchard, 1021; Leonard, 1559; Savage, 2128.
Niagara formation, Silurian, Maryland: Clark and Mathews, 488.
Niagara formation, Silurian, New York: Hartnagel, 1085.
Niagara, Silurian, Mississippi Valley: Fairchild, 835.
Niagara limestone, Silurian, Wisconsin: Grant, 1017.
Niagara series, Silurian, Iowa: Norton, 1805.
Niagaran limestone, Silurian, Illinois: Weller, 2517, 2523, 2524.
Nichols slate, Cambrian, Tennessee: Keith, 1354.
Nicola group, Triassic, British Columbia: Brooks, 313.
Nikolai greenstone, Alaska: Brooks, 313.
Nineveh limestone, Carboniferous, Appalachian region: Stevenson, 2295.
Nineveh limestone, Carboniferous, Pennsylvania: Clapp, 476.
Nineveh limestone, Carboniferous, Pennsylvania, Ohio, and West Virginia: Griswold and Munn, 1048.
Nineveh limestone, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Niobrara formation, Cretaceous, Montana: Rowe, 2090.
Niobrara formation, Cretaceous, Nebraska: Condra, 570.
Niobrara formation, Cretaceous, North Dakota: Leonard, 1563.
Niobrara formation, Cretaceous, Wyoming: Darton and O'Harra, 656; Veatch, 2440.
Nipigon, pre-Cambrian, Ontario: Silver, 2212.
Nisconlith series, British Columbia: Dawson, 686.
Nisconlith series, Canada: Walcott, 2470.
Nisconlith series, Cambrian, Yukon Territory: Brooks, 313.
Noah Parker horizon, Cambrian, Vermont: Edson, 774.
Nolichucky shale, Cambrian, Tennessee: Keith, 1354.
Nolichucky shale, Cambrian, Virginia: Bassler, 158.
Nome series, Alaska: Moffit, 1764.
Nome series, Silurian, Alaska: Brooks, 313.
Nonesuch formation, Algonkian, Michigan: Gordon and Lane, 985.
Nonesuch formation, Cambrian, Michigan: Lane and Seaman, 1518.
Nonushuk series, Cretaceous, Alaska: Brooks, 313.
Nordheimer formation, Carboniferous?, California: Hershey, 1133.
Norfolk formation, Tertiary, Virginia: Clark and Miller, 489.
Norfolk Basin series, Massachusetts: Mansfield, 1674.
Northbridge gneiss, pre-Cambrian, Rhode Island: Emerson and Perry, 790.
North Haven greenstone, Cambrian, Maine: Smith *et al.*, 2241.

North Mound quartzite, pre-Cambrian, Wisconsin: Weidman, 2512.
North Park formation, Tertiary, Wyoming: Veatch, 2440.
Norton formation, Carboniferous, Virginia: Stone, 2311.
Nosoni formation, Carboniferous, California: Diller, 721.
Nottely quartzite, Cambrian, North Carolina: Keith, 1352.
Nunda formation, Devonian, New York: Williams, 2583.
Nunda formation, Devonian, Pennsylvania: Butts, 367.
Nussbaum formation, Tertiary, Colorado: Darton, 648; Fisher, 869.
Obispo formation, Panama: Howe, 1244.
Oconee zone, Archean, South Carolina: Sloan, 2218.
Ogden quartzite, Ordovician, Utah: Emmons, 798; Weeks, 2506.
Ogishke conglomerate, Algonkian, Minnesota: Abbott, 1.
Ohio shale, Devonian, Kentucky: Foerste, 883.
Oldham limestone, Silurian, Kentucky: Foerste, 883, 884.
Onaping tuff, pre-Cambrian, Ontario: Coleman, 539, 546.
Oneida conglomerate, Silurian, New York: Clarke, 494; Hartnagel, 1083.
Oneonta beds, Devonian, New York: Grabau, 991.
Oneota formation, Ordovician, Iowa: Calvin, 387, 388.
Oneota formation, Ordovician, upper Mississippi Valley: Bain, 99.
Oneota limestone, Ordovician, Iowa: Beyer and Williams, 234.
Onondaga limestone, Devonian, New York: Grabau, 991; Luther, 1633.
Ontario quartzite, Carboniferous, Utah: Jenney, 1296.
Onwatin slate, pre-Cambrian, Ontario: Coleman, 539, 546.
Orange phyllite, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Orca series, Alaska: Brooks, 313.
Oread limestone, Carboniferous, Kansas: Beede and Rogers, 181; Wooster, 2636.
Oregon, Ordovician, Kentucky: Miller, 1748.
Oriskany, Virginia: Eckel, 765.
Oriskany formation (Monterey), Devonian, Maryland: Clark and Mathews, 488.
Oriskany formation, Devonian, New York: Grabau, 991; Hartnagel, 1084; Williams, 2583.
Oriskany sandstone, Devonian, New York: Luther, 1633.
Oriskany sandstone, Devonian, Pennsylvania: Butts, 367.
Oriskany sandstone, Devonian, West Virginia: Grimsley, 1044.
Osage, Mississippian, Illinois: Fenneman, 860.
Osage formation, Carboniferous, Iowa: Calvin, 387.
Osage limestones, Mississippian, Illinois: Bowman and Reeds, 277.
Osage limestone, Mississippian, Iowa: Beyer and Williams, 234.
Osage shales, Carboniferous, Kansas: Wooster, 2636.
Osceola amygdaloid, Algonkian, Michigan: Lane, 1509.
Osoyoos granodiorite, Jurassic, Cascade Mountains: Daly, 632.
Oswego limestone, Carboniferous, Kansas: Wooster, 2636.
Otis limestone, Devonian, Iowa: Norton, 1805.
Ouray limestone, Devonian and Carboniferous (Mississippian), Colorado: Cross *et al.*, 607.
Outer conglomerate, Algonkian, Michigan: Gordon and Lane, 985.
Outer conglomerate, Cambrian, Michigan: Lane and Seaman, 1518.
Owen beds, Devonian, Iowa: Williams, 2588.
Oxmoor sandstone, Mississippian, Alababama: Burchard, 355.
Painterhood limestone, Pennsylvanian, Kansas: Schrader and Haworth, 2144.
Paint Lick bed, Ordovician, Kentucky: Foerste, 884.
Palisade conglomerates, Tertiary, Alaska: Brooks, 313.
Pamunkey group, Eocene, Maryland: Clark and Mathews, 488; Shattuck, 2188; Shattuck *et al.*, 2193.
Pamunkey group, Tertiary, Maryland and Delaware: Miller, 1749.
Parachucla shale, Oligocene, South Carolina: Sloan, 2218.
Paris, Ordovician, Kentucky: Miller, 1748.
Paris shale, Carboniferous, Arkansas: Collier, 556.
Park shale, Cambrian, Montana: Emmons, 806.
Park granite, Tertiary, Cascade Mountains: Daly, 632.
Park City formation, Carboniferous, Utah: Boutwell, 271.
Parkman sandstone, Cretaceous, Wyoming: Darton, 644–647.
Parma sandstone, Carboniferous, Michigan: Cooper, 575; Lane, 1516.
Parrish limestone, Devonian, New York: Luther, 1634.
Parsons formation, Pennsylvanian, Kansas: Schrader and Haworth, 2144; Wooster, 2636.
Pascagoula formation, Pliocene, Alabama: Smith, 2229.
Pascagoula formation, Tertiary, Gulf region: Smith, 2226.
Pascagoula formation, Tertiary, Mississippi: Crider, 595; Crider and Johnson, 599.

Paspotansa member, Eocene, Maryland: Shattuck *et al.*, 2193.
Patapsco formation, Cretaceous, Maryland: Clark and Mathews, 488; Shattuck *et al.*, 2193.
Patapsco formation, Cretaceous, Maryland and Delaware: Miller, 1749.
Patapsco formation, Cretaceous, Virginia: Clark and Miller, 489.
Patton shale, Mississippian, Pennsylvania: Butts, 368.
Patuxent formation, Jurassic?, Maryland: Clark and Mathews, 488.
Patuxent formation, Jurassic?, Virginia: Clark and Miller, 489.
Patuxent formation, Jurassic? and Cretaceous, Maryland and District of Columbia: Shattuck *et al.*, 2193.
Pawnee limestone, Pennsylvanian, Kansas: Schrader and Haworth, 2144; Wooster, 2636.
Peachbottom slate, Algonkian, Maryland: Clark and Mathews, 488.
Pearisburg limestone, Ordovician, Virginia: Bassler, 158.
Pecosian series, Pliocene, New Mexico: Keyes, 1390.
Pee Dee marl, Miocene, South Carolina: Sloan, 2218.
Peekskill granite, Ordovician, New York: Berkey, 207.
Pelham (Trenton) limestone, Ordovician, Alabama: Smith, 2229.
Pella beds, Mississippian, Iowa: Beyer and Williams, 234.
Pelly gneisses, Alaska: Brooks, 313.
Peña Blanca marls, Oligocene: Howe, 1244.
Pennington shale, Carboniferous, Virginia: Bassler, 158.
Penobscot formation, Cambrian: Smith *et al*, 2241.
Peorian, Quaternary, Iowa: Calvin, 387.
Percha shale, Devonian, New Mexico: Gordon, 981.
Perry beds, Devonian, Canada: Ells, 784.
Perryville, Ordovician, Kentucky: Miller, 1748.
Peshastin formation, pre-Tertiary, Washington: Smith and Calkins, 2240.
Piercefield gneiss, New York: Cushing, 614.
Pierre formation, Cretaceous, Canada: Dowling, 735.
Pierre shale, Cretaceous, Colorado: Darton, 648; Fisher, 869.
Pierre shale, Cretaceous, North Dakota: Leonard, 1560, 1563.
Pierre shale, Cretaceous, Nebraska: Condra, 570.
Pierre shale, Cretaceous, Wyoming: Darton, 642, 644–647; Darton and O'Harra, 656; Fisher, 873.
Pierre shales, Cretaceous, Montana: Brown, 325; Leonard, 1564.
Pikes Peak granite, Colorado: Graton, 1026.
Pilgrim limestone, Devono-Silurian, Montana: Emmons, 806.
Piney formation, Cretaceous, Wyoming: Darton, 644–647.
Piqua limestone, Pennsylvanian, Kansas: Schrader and Haworth, 2144; Wooster, 2636.
Piscataway member, Eocene, Maryland: Shattuck *et al.*, 2193.
Pit formation, Triassic, California: Diller, 721.
Pitkin limestone, Mississippian, Arkansas: Purdue, 1971.
Pitkin limestone, Mississippian, Indian Territory: Taff, 2332.
Pittsburg limestone, Carboniferous, Pennsylvania: Stevenson, 2294; Woolsey, 2634.
Pittsburg limestones, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Pittsburg red shales, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Pittsburg sandstone, Carboniferous, Appalachian region: Stevenson, 2295.
Pittsburg sandstone, Carboniferous, Pennsylvania: Clapp, 475.
Pittsburg sandstone, Carboniferous, West Virginia: Grimsley, 1046.
Pittsford shale, Silurian, New York: Hartnagel, 1085.
Plainfield quartz schist, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Platteville formation, Ordovician, Iowa: Burchard, 353.
Platteville limestone, Ordovician, Iowa: Calvin, 387, 388.
Platteville limestone, Ordovician, upper Mississippi Valley: Bain, 99; Sardeson, 2122.
Platteville (Trenton), Ordovician, Mississippi Valley: Davis, 663.
Platteville limestone, Ordovician, Wisconsin: Grant, 1017; Grant and Burchard, 1021.
Platteville stage, Ordovician, Iowa: Beyer and Williams, 234.
Plattin limestone, Ordovician, Illinois: Weller, 2523.
Pleasonton beds, Carboniferous, Kansas: Wooster, 2636.
Pleasonton shale, Pennsylvanian, Missouri: Shepard, 2194.
Plum Creek clay, Silurian, Kentucky: Foerste, 883, 884.
Plum Point marls, Miocene, Maryland: Shattuck *et al.*, 2193.
Plum Point marls, Tertiary, Maryland: Shattuck, 2185.
Pocono formation, Carboniferous, Pennsylvania: Butts, 368; Clapp, 475, 477.
Pocono sandstone, Lower Carboniferous, Pennsylvania: Barrell, 150.
Pocono sandstone, Carboniferous, West Virginia: Grimsley, 1044.
Pocono formation, Mississippian, Maryland: Clark and Mathews, 488.
Pogonip limestone, Ordovician, California and Nevada: Ball, 120.

Point Pleasant formation, Ordovician, Ohio and Kentucky: Bassler, 156.
Poison Canyon formation, Cretaceous?, Colorado: Darton, 648.
Polk Bayou limestone, Ordovician, Arkansas: Purdue, 1970.
Pomfret phyllite, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Poor Mountain zone, Cambrian?, South Carolina: Sloan, 2218.
Portage member, Devonian, Maryland: Clark and Mathews, 488.
Port Clarence limestone, Silurian, Alaska: Brooks, 313.
Porters Creek clay, Cretaceous, Mississippi: Crider, 598.
Porters Creek clay, Tertiary, Mississippi: Crider, 595; Crider and Johnson, 599.
Porters Creek (Flatwoods) clay, Eocene, Mississippi: Logan, 1608.
Porters Creek formation, Tertiary, Illinois: Purdy and DeWolf, 1973.
Porters Creek formation, Tertiary, Missouri: Shepard, 2194.
Porters Creek formation, Tertiary, Tennessee, Kentucky, and Illinois: Glenn, 971.
Port Ewen limestone, Devonian, New York: Grabau, 991.
Port Hudson formation, Quaternary, Mississippi: Crider, 595; Crider and Johnson, 599.
Port Hudson formation, Quaternary, Louisiana and Arkansas: Veatch, 2436.
Port Renfrew series, Vancouver Island: Hall, 1064.
Potapaco member, Eocene, Maryland: Shattuck *et al.*, 2193.
Potem formation, Jurassic, California: Diller, 721.
Potomac formation, Cretaceous, Mississippi: Logan and Hand, 1609.
Potomac formation, Cretaceous, South Carolina: Pugh, 1963.
Potomac group, Cretaceous, Maryland and Delaware: Miller, 1749.
Potomac group, Jurassic? and Cretaceous, Maryland: Shattuck *et al.*, 2193.
Potomac group, Jurassic-Cretaceous, Maryland: Clark and Mathews, 488.
Potosi volcanic series, Colorado: Cross *et al.*, 607.
Potsdam sandstone, Cambrian, Illinois: Weller, 2517, 2524.
Potsdam sandstone, Cambrian, Wisconsin: Grant, 1017; Weidman, 2512.
Potsdam series, Cambrian, Iowa: Beyer and Williams, 234.
Potsdam, Ordovician, Mississippi Valley: Davis, 663.
Pottsville conglomerate, Lower Carboniferous, Pennsylvania: Barrell, 150.
Pottsville formation, Carboniferous, Ohio: Carney, 427.
Pottsville formation, Carboniferous, Pennsylvania: Butts, 368; Clapp, 475, 477; Woolsey, 2634.
Pottsville formation, Carboniferous, Pennsylvania, Ohio, and West Virginia: Griswold and Munn, 1048.
Pottsville formation, Pennsylvanian, Maryland: Clark and Mathews, 488.
Pottsville series, Carboniferous, West Virginia: Grimsley, 1044.
Poughquag quartzite, Connecticut: Gregory, 1034.
Poughquag quartzite, Cambrian, Connecticut: Gregory and Robinson, 1038.
Poughquag quartzite, Cambrian, New York: Berkey, 207.
Poughquag quartzite, Cambro-Ordovician, Connecticut: Hobbs, 1185.
Powers Bluff quartzite, pre-Cambrian, Wisconsin: Weidman, 2512.
Prairie du Chien formation, Ordovician, upper Mississippi Valley: Bain, 99.
Prairie du Chien limestone, Ordovician, Iowa: Beyer and Williams, 234.
Prairie du Chien formation, Ordovician, Wisconsin: Grant and Burchard, 1021.
Prattsburg shales and flags, Devonian, New York: Luther, 1634.
Pre-Kansan, Quaternary, Iowa: Calvin, 387.
Preston formation, Cretaceous, Arkansas: Veatch, 2436.
Preston gabbro-diorite, Connecticut: Gregory and Robinson, 1038.
Prichard (?) formation, pre-Cambrian, Montana: Emmons, 806.
Prichard slate, Algonkian, Montana: Walcott, 2470.
Prospect porphyritic gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Prospect Mountain quartzite, Cambrian?, Nevada and California: Ball, 120.
Prosperity limestone, Carboniferous, Pennsylvania: Clapp, 475.
Prosperity limestone, Carboniferous, Pennsylvania, Ohio, and West Virginia: Griswold and Munn, 1048.
Prout limestone, Devonian, Ohio: Stauffer, 2277.
Providence Cove beds, Vancouver Island: Hall, 1064.
Puente shale, Miocene, California: Eldridge and Arnold, 779.
Puerco, Tertiary, Wyoming: Veatch, 2439.
Puerco marls, Eocene, New Mexico: Keyes, 1388.
Puerco marl, Eocene, Colorado and New Mexico: Shaler, 2176.
Puerco marls, Eocene, New Mexico: Keyes, 1390.
Puget group, Cretaceous, Washington: Arnold, 56.
Puget group, Tertiary, British Columbia: Brooks, 313.
Pulliam formation, Cretaceous, Texas: Udden, 2408.
Purgatory conglomerate, Massachusetts: Mansfield, 1674.
Purisima formation, Tertiary, California: Arnold, 57.

Putnam gneiss, Connecticut: Gregory, 1034; Gregory and Robinson, 1038.
Putnam Hill limestone, Carboniferous, Pennsylvania: Stevenson, 2294.
Quadrant (?) formation, Carboniferous, Montana: Emmons, 806.
Quadrant formation, Mississippian, Montana: Rowe, 2090.
Quartermaster formation, Permian, Texas: Gould, 986, 987.
Quebec group, Canada: Young, 2660.
Queen Charlotte group, Cretaceous, British Columbia: Brooks, 313.
Quinaielt formation, Tertiary, Washington: Arnold, 56.
Quincy group, early Carboniferous, or late pre-Carboniferous: Emerson and Perry, 790.
Racine limestone, Silurian, Wisconsin: Alden, 23.
Rampart series, Devonian, Alaska: Brooks, 313; Prindle, 1956.
Ramsay Lake graywacke conglomerate, pre-Cambrian, Ontario: Coleman, 539.
Rancocas formation, Cretaceous, Maryland and Delaware: Miller, 1749.
Raritan clay, Cretaceous, New Jersey: Weller, 2520.
Raritan formation, Cretaceous, Maryland: Clark and Mathews, 488; Shattuck *et al.*, 2193.
Raritan formation, Cretaceous, Maryland and Delaware: Miller, 1749.
Raritan, Cretaceous, New York: Veatch, 2434.
Rattlesnake beds, Cretaceous, Texas: Udden, 2409.
Ravalli (?) formation, pre-Cambrian, Montana: Emmons, 806.
Ravalli series, Algonkian, Montana: Walcott, 2470.
Red Bank sand, Cretaceous, New Jersey: Weller, 2520.
Red Beds, Permian, New Mexico: Ordóñez, 1831.
Red Beds, Triassic ?, Colorado; Darton, 648; Gale, 922.
Red Bluff formation, Quaternary, California: Diller, 721.
Red Bluff sandstones, Permian, Kansas: Wooster, 2636.
Red Mountain formation (Clinton), Silurian, Alabama: Smith, 2229.
Redstone limestone, Carboniferous, Appalachian region: Stevenson, 2295.
Redstone limestone, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Remmel granodiorite, Jurassic, Cascade Mountains: Daly, 632.
Revett quartzite, Algonkian, Montana: MacDonald, 1658.
Rhinestreet black shale, Devonian, New York: Luther, 1633, 1634.
Rib Hill quartzite, pre-Cambrian, Wisconsin: Weidman, 2512.
Richmond division of the Cincinnatian, Ordovician, Illinois: Weller, 2517, 2524.
Richmond limestone, Ordovician, Illinois: Weller, 2522.
Richmond limestone and shales, Ordovician, Missouri: Bowman and Reeds, 277.
Ripley formation, Cretaceous, Alabama: Smith, 2229.
Ripley formation, Cretaceous, Illinois: Purdy and DeWolf, 1973.
Ripley formation, Cretaceous, Mississippi: Crider, 595; Crider and Johnson, 599; Logan, 1608.
Ripley formation, Cretaceous, North Carolina: Stephenson, 2281.
Ritchie red beds, Carboniferous, Appalachian region: Stevenson, 2295.
Riverside sandstone, Mississippian, Indiana: Reagan, 1998.
Roan gneiss, Archean, North Carolina: Keith, 1352, 1354.
Rochester shale, Silurian, New York: Bassler, 156; Hartnagel, 1085.
Rockcastle, Carboniferous, Appalachian region: Stevenson, 2295.
Rockwood (Clinton), Virginia: Eckel, 765.
Rockwood formation, Silurian, West Virginia: Grimsley, 1044.
Rocky Mountain quartzite, Carboniferous, Alberta: Dowling, 736.
Rogersville limestone, Carboniferous, Appalachian region: Stevenson, 2295.
Rogersville shale, Cambrian, Virginia: Bassler, 158.
Rome shales, Cambrian, Georgia: Watson, 2483.
Romney formation, Devonian, Maryland: Clark and Mathews, 488.
Romney shale, Devonian, West Virginia: Grimsley, 1044.
Rondout formation, Silurian, New York: Hartnagel, 1084.
Rondout limestone, Silurian, New York: Grabau, 991.
Rosalie granite, pre-Cambrian, Colorado: Ball, 118.
Rosebud beds, Tertiary, South Dakota: Matthew, 1702.
Rosendale cement rock, Silurian, New York: Grabau, 991.
Rosiclare sandstone, Mississippian, Illinois: Weller, 2523.
Roslyn formation, Tertiary, Washington: Smith and Calkins, 2240.
Roubidoux sandstone, Cambro-Ordovician, Missouri: Shepard, 2194.
Rove slates, Algonkian, Minnesota: Abbott, 1.
Roxbury conglomerate, Carboniferous?, Massachusetts: Mansfield, 1674.
Russell shales, Cambrian, Virginia: Bassler, 158.
Ruth limestone, Carboniferous, Nevada: Lawson, 1526.
Rutledge limestone, Cambrian, Virginia: Bassler, 158.
Sabine formation, Tertiary, Arkansas and Louisiana: Veatch, 2436, 2437,

Sabine stage, Eocene, Louisiana: Harris, 1079.
Saddlehorse lentil, Permian, Texas: Gould, 987.
Saginaw formation, Carboniferous, Michigan: Cooper, 575; Lane, 1516.
St. Clair limestone, Silurian, Arkansas: Purdue, 1970.
St. Clair marble, Silurian, Indian Territory; Taff, 2332.
St. Croix formation, Cambrian, Iowa: Calvin, 387; Leonard, 1559.
St. Croix sandstone, Cambrian, Iowa: Beyer and Williams, 234.
St. Joe limestone member, Mississippian, Arkansas: Purdue, 1971.
St. Joe marble, Carboniferous, Arkansas: Purdue, 1970.
St. Joe member, Mississippian, Indian Territory: Taff, 2332.
St. Lawrence formation, Cambrian, Iowa: Calvin, 387.
St. Lawrence limestone, Cambrian, Iowa: Beyer and Williams, 234.
St. Louis limestone, Carboniferous, Iowa: Calvin, 387.
St. Louis limestone, Mississippian, Illinois: Bowman and Reeds, 277; Fenneman, 860; Weller, 2523.
St. Louis limestone, Mississippian, Mississippi: Crider, 595.
St. Louis limestone, Mississippian, Missouri: Shepard, 2194.
St. Louis stage, Mississippian, Iowa: Beyer and Williams, 234.
St. Mary's formation, Miocene, Maryland: Clark and Mathews, 488; Shattuck, 2185, 2188, 2191.
St. Mary's formation, Tertiary, Virginia: Clark and Miller, 489.
St. Peter sandstone, Cambrian, Michigan: Lane and Seaman, 1518.
St. Peter sandstone, Cambro-Ordovician, Missouri: Shepard, 2194.
St. Peter sandstone, Ordovician, Illinois: Weller, 2517, 2524.
St. Peter formation, Ordovician, Iowa: Calvin, 387, 388; Leonard, 1559.
St. Peter sandstone, Ordovician, upper Mississippi Valley: Bain, 99; Berkey, 205; Davis, 663.
St. Peter sandstone, Ordovician, Wisconsin: Alden, 23; Grant, 1017; Grant and Burchard, 1021.
St Peters sandstone, Ordovician, Illinois: Bowman and Reeds, 277; Weller, 2523.
St. Regis formation, Algonkian, Montana: MacDonald, 1658; Walcott, 2470.
St. Stephen's limestone, Eocene, Alabama: Smith, 2229.
St. Stephen's limestone, Tertiary, Gulf region: Smith, 2226.
Salem limestone, Carboniferous, Indiana: Cumings and Beede, 612.
Salem (Bedford) limestone, Mississippian, Indiana: Reagan, 1998.
Salina formation, Silurian, New York: Hartnagel, 1085.
Salina member, Silurian, Maryland: Clark and Mathews, 488.
Salkehatchie marl, Miocene, South Carolina: Sloan, 2218.
Salt Plain shales, Permian, Kansas: Wooster, 2636.
Saltsburg sandstone, Carboniferous, Pennsylvania: Butts, 368.
Saltzburg sandstone, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Saluda zone, Archean, South Carolina: Sloan, 2218.
San Bruno limestone, California: Crandall, 591.
Sandia beds, Carboniferous, New Mexico: Gordon 982,
Sandia formation, Carboniferous, New Mexico: Keyes, 1377.
Sandusky formation, Devonian, Ohio: Swartz, 2329.
Sangamon, Quaternary, Iowa: Calvin, 387.
San Juan tuff, Colorado: Cross *et al.*, 607.
Sankaty formation, Quaternary, New York: Veatch, 2434.
Sankaty Head beds, Pleistocene, Nantucket Island: Wilson, 2610.
San Lorenzo, Tertiary, California: Arnold, 57.
San Miguel beds of Eagle Pass formation, Cretaceous, Texas: Udden, 2408.
San Pablo formation, Tertiary, California: Prindle, 1956.
San Pedro formation, Pleistocene, California: Prindle, 1956.
San Pedro shales, California: Crandall, 591.
Santa Fe sands, Miocene, New Mexico, Keyes, 1388, 1390.
Santee marl, Eocene, South Carolina: Sloan, 2218.
Saratoga formation, Cretaceous, Arkansas: Veatch, 2436.
Savanna formation, Carboniferous, Arkansas: Collier, 556.
Scarborough beds of Toronto formation, Quaternary, Canada: Coleman, 547.
Schoharie grit, Devonian, New York: Grabau, 991.
Scotland schist, Connecticut: Gregory, 1034: Gregory and Robinson, 1038.
Sea Island sands, Pleistocene, South Carolina: Sloan, 2218.
Seekonk conglomerate, Massachusetts: Mansfield, 1674.
Selkirk series, British Columbia: Dawson, 686.
Sellersburg beds, Devonian, Indiana: Stauffer, 2278.
Sellersburg limestone, Devonian, Indiana: Blatchley, 246.
Selma chalk, Cretaceous, Alabama: Smith, 2229.
Selma chalk, Cretaceous, Mississippi: Crider, 595, 598; Crider and Johnson, 599; Logan, 1608.

Selma clay, Cretaceous, Tennessee: Glenn, 971.
Sespe formation, Eocene-Oligocene, California: Arnold, 63; Eldridge and Arnold, 779.
Sespe formation, Tertiary, California: Arnold and Anderson, 67.
Sespe sandstone, Eocene or Oligocene, California: Arnold and Anderson, 66.
Setters quartzite, Algonkian, Maryland: Clark and Mathews, 488.
Seven Sisters sandstone member, Carboniferous, Kentucky: Ashley and Glenn, 77.
Severy shales, Carboniferous, Kansas: Wooster, 2636.
Sevier shales, Ordovician, Virginia: Bassler, 158.
Sewickley limestone, Carboniferous, West Virginia: Grimsley, 1044, 1046.
Sewickley sandstone, Carboniferous, Appalachian region: Stevenson, 2295.
Sewickley sandstone, Carboniferous, West Virginia: Grimsley, 1046.
Shady limestone, Cambrian, Tennessee: Keith, 1354.
Shakopee formation, Ordovician, Iowa: Calvin, 387, 388.
Shakopee formation, Ordovician, upper Mississippi Valley: Bain, 99.
Shakopee limestone, Ordovician, Iowa: Beyer and Williams, 234.
Shawangunk conglomerate, Silurian, New York: Hartnagel, 1084.
Shawangunk grit, Silurian, New York: Clarke, 499; Grabau, 991.
Shenandoah limestone, Cambro-Ordovician, Maryland: Clark and Mathews, 488.
Shenandoah limestone, Cambro-Ordovician, Pennsylvania: Stose, 2318.
Shenandoah limestone, Cambro-Ordovician, West Virginia: Grimsley, 1044.
Shenandoah limestone group, Cambrian, Virginia: Bassler, 158.
Sherburne formation, Devonian, New York: Grabau, 991.
Sherburne flagstone member, Devonian, New York: Williams, 2583.
Shinarump conglomerate, Triassic, Utah: Cross, 604; Lee, 1544.
Shuswap series, British Columbia: Dawson, 686.
Shuswap series, Archean, Yukon Territory: Brooks, 313.
Siamo slate, pre-Cambrian, Michigan: Lane and Seaman, 1518.
Siebert Lake beds, Pliocene, Nevada: Ball, 120.
Sillery formation, Cambrian, Canada: Young, 2660.
Silver Creek hydraulic limestone, Devonian, Indiana: Blatchley, 246.
Silver Pipe limestone, Mississippian, New Mexico: Gordon, 981.
Silver Plume granite, pre-Cambrian, Colorado: Ball, 118.
Silver Terrace sandstone, California: Crandall, 591.
Silverton volcanic series, Colorado: Cross *et al.*, 607.
Similkameen granite, Tertiary, Cascade Mountains: Daly, 632.
Sioux quartzite, pre-Cambrian, Iowa: Calvin, 387.
Sioux quartzite, Proterozoic, Iowa: Beyer and Williams, 234.
Skagit series, Alaska: Brooks, 313.
Skaneateles shale, Devonian, New York: Luther, 1633.
Skolai volcanics, Triassic, Alaska: Brooks, 313.
Skwentna complex, Alaska: Brooks, 313.
Smithfield limestone member, Cambrian, Rhode Island: Emerson and Perry, 790.
Smith River beds, Tertiary, Montana: Rowe, 2090.
Snoqualmie granodiorite, Tertiary, Washington: Smith and Calkins, 2240.
Snowbird formation, Cambrian, Tennessee: Keith, 1354.
Socorran series, Carboniferous, New Mexico: Keyes, 1377.
Sodus shale, Silurian, New York: Clarke, 494; Hartnagel, 1085.
Soudan formation, Archean, Minnesota: Abbott, 1.
Southgate member, Ordovician, Ohio and Kentucky: Bassler, 156.
Spadra shale, Carboniferous, Arkansas: Collier, 556.
Spearfish formation, Triassic, Wyoming: Darton and O'Harra, 656.
Spergen limestone, Mississippian, Illinois: Fenneman, 860; Weller, 2523.
Spergen limestone, Mississippian, Missouri: Shepard, 2194.
Spergen Hill limestone, Mississippian, Illinois: Bowman and Reeds, 277.
Spokane formation, Algonkian, Montana: Barrell, 149.
Spokane shale, Algonkian, Montana: Rowe, 2090.
Spring Creek granite, Colorado: Graton, 1026.
Springvale beds, Mississippian, Iowa: Beyer and Williams, 234.
Square Lake limestone, Devonian, New York: Grabau, 991.
Stafford limestone, Devonian, New York: Luther, 1633.
Standish shales, Devonian, New York: Luther, 1634.
Stanton limestone, Carboniferous, Kansas: Beede and Rogers, 181; Wooster, 2636.
State Quarry limestone, Devonian, Iowa: Beyer and Williams, 234; Calvin, 387.
Stennett limestone, Pennsylvanian, Iowa: Beyer and Williams, 234.
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Three Forks shale, Devonian, Montana: Raymond, 1989.
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Vicksburg limestone, Tertiary, Gulf region: Smith, 2226.
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UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

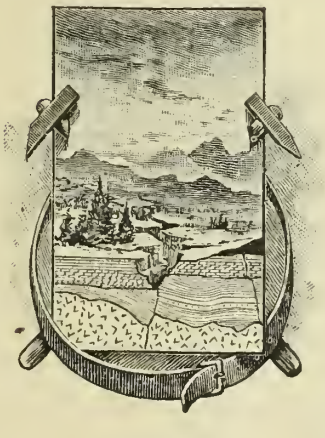
BULLETIN 373

THE SMOKELESS COMBUSTION OF COAL IN BOILER PLANTS

WITH A CHAPTER ON CENTRAL HEATING PLANTS

BY

D. T. RANDALL AND H. W. WEEKS



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THE SMOKELESS COMBUSTION OF COAL IN BOILER PLANTS.

By D. T. Randall and H. W. Weeks.

INTRODUCTION.

THE PROBLEM AND ITS SOLUTION.

The burning of coal without smoke is a problem which concerns the Government directly because of the advantages of smokeless combustion both in public buildings and on naval vessels. In addition, smoke abatement is a factor in conserving the fuel resources of the United States. Hence, as part of its general investigation of the best methods of utilizing the coals of this country, the United States Geological Survey has made extended tests to determine the conditions necessary for the smokeless combustion of bituminous coal in boiler plants, and has obtained information relating to the setting and operation of boilers at industrial establishments where coal high in volatile matter is burned without smoke.

Bulletin 334, a preliminary report on the subject of smoke abatement, treated the problem from a theoretical point of view, detailing the steps that are now being taken by municipalities, manufacturers, and citizens to stop the evil, also showing the possibility of a clean city. The present bulletin not only shows that bituminous coals high in volatile matter can be burned without smoke, but also that large plants carrying loads that fluctuate widely, where boilers over banked fires must be put into service quickly and fires forced to the capacity of their units, can be operated without producing smoke that is objectionable. Proper equipment, efficient labor, and intelligent supervision are the necessary factors.

INVESTIGATION OF INDUSTRIAL PLANTS.

SCOPE AND PURPOSE.

In the investigation of industrial establishments a study was made of the conditions in thirteen of the larger cities in Illinois, Indiana, Kentucky, Maryland, Michigan, Missouri, New York, Ohio, and Pennsylvania, between 400 and 500 plants being inspected. Sufficient information was collected to make the data from 284 plants of value

for this report. In nearly every city visited coal was supplied from points both in and out of the State, so that although but nine States were visited, the facts ascertained apply to coals from a greater number.

The main purpose of the inspection was to obtain a better knowledge as to the influence on smoke production of furnace design and of the conditions under which combustion takes place.

SUMMARY OF CONCLUSIONS.

The results of this investigation are set forth in detail on later pages of this volume. The general conclusions to be drawn can be summarized in a few paragraphs.

Smoke prevention is possible. There are many types of furnaces and stokers that are operated smokelessly.

Any one kind of apparatus is effective only if so set under boilers that the principles of combustion are respected. The value to the average purchaser of a manufacturer's requirement on this point lies in the fact that he is thus reasonably certain of good installation. A good stoker or furnace poorly set is of less value than a poor stoker or furnace well set. Good installation of furnace equipment is necessary for smoke prevention.

Stokers or furnaces must be set so that combustion will be complete before the gases strike the heating surface of the boiler. When partly burned gases at a temperature of, say, 2,500° F., strike the tubes of a boiler at, say, 350° F., combustion is necessarily hindered and may be entirely arrested. The length of time required for the gases to pass from the coal to the heating surface probably averages considerably less than one second, a fact which shows that the gases and air must be intimately mixed when large volumes of gas are distilled, as at times of hand firing, or the gas must be distilled uniformly, as in a mechanical stoker. By adding mixing structures to a mechanical stoker equipment both the amount of air required for combustion and the distance from the grates to the heating surface may be reduced for the same capacity developed. The necessary air supply can also be reduced by increasing the rate of combustion.

No one type of stoker is equally valuable for burning all kinds of coal. The plant which has an equipment properly designed to burn the cheapest coal available will evaporate water at the least cost.

Although hand-fired furnaces can be operated without objectionable smoke, the fireman is so variable a factor that the ultimate solution of the problem depends on the mechanical stoker—in other words, the personal element must be eliminated. There is no hand-fired furnace from which, under average conditions, as good results can be obtained as from many different patterns of mechanical stoker, and of two equipments the one which will require the less attention

from the fireman gives the better results. The most economical hand-fired plants are those that approach most nearly to the continuous feed of the mechanical stoker.

The small plant is no longer dependent on hand-fired furnaces, as certain types of mechanical stokers can be installed under a guaranty of high economy, with reduction of labor for the fireman.

In short, smoke prevention is both possible and economical.

PERSONNEL.

This investigation was carried out under the direction of D. T. Randall, L. F. Beers and H. W. Weeks procuring most of the data. Mr. Weeks has also prepared a large portion of the report. In the collection of the information much assistance was given by the city smoke inspectors, by manufacturers of boiler-room equipment, and by the owners of the plants visited, and to them especial thanks are hereby extended for their active cooperation.

METHOD OF COLLECTING DATA.

On entering a city a list was obtained of the plants where mechanical stokers or special devices for hand-fired furnaces were in operation without smoke. Smoke observations were taken on the stacks at these plants, or records at the smoke inspector's office were reviewed to determine the plants to be visited. The stack was always watched at times when the plant was running under average conditions, and always without the knowledge of the engineer or fireman. The length of the observations varied from one hour to ten hours, although a one-hour record determined whether a stack was good or bad. The observer usually checked this record by watching the stack during several shorter periods while he was in the city.

During the visit to each plant an attempt was made to obtain data enough so that the furnace and boiler setting could be duplicated. All information except that in regard to drafts and furnace measurements was supplied by the manager or the engineer in charge of the plant. The engineer usually knew the approximate amount of coal burned per day on heavy and light loads and the number of boilers used to carry the load. Draft readings were taken to obtain the drop in draft through the boiler and to learn the effective draft which burned the coal. Special notice was taken of the methods of operation to determine whether in case the plant was duplicated the same results could be expected if it was operated by the average fireman.

SIZES OF COAL.

The size of the coal which was being burned at the various plants inspected is stated in the tables as run-of-mine, sized egg or nut, and screenings, except for the Illinois plants, where the sizes are given

as Nos. 1, 2, 3, 4, or 5. The standard for sizing coal is not uniform over the whole State of Illinois, but in Williamson County washed coal is passed over screens with round openings and is sized and numbered as follows:

No. 1, coal passing through 3-inch screen and over $1\frac{3}{4}$-inch screen.
No. 2, coal passing through $1\frac{3}{4}$-inch screen and over 1-inch screen.
No. 3, coal passing through 1-inch screen and over $\frac{3}{4}$-inch screen.
No. 4, coal passing through $\frac{3}{4}$-inch screen and over $\frac{1}{4}$-inch screen.
No. 5, coal passing through $\frac{1}{4}$-inch screen.

About half the washeries in Illinois size coal according to the above scheme.

DEFINITION OF BOILER HORSEPOWER.

To determine the percentage of the rated capacity being developed it was necessary to assume the amount of coal each plant burned per boiler horsepower per hour. To a mechanical engineer the term "boiler horsepower" suggests two things—a measure of the rate of work and a measure of the capacity of the boiler.

Rate of work.—The measure of the rate of work of a boiler is based on an arbitrary unit of an evaporation of 30 pounds of water per hour from a feed-water temperation of 100° F. into steam at 70 pounds gage pressure. This unit is termed a boiler horsepower, and was suggested as of possible value at a time when a good engine had a water rate of about 30 pounds per hour. It became so widely used that in 1885 it was adopted by the American Society of Mechanical Engineers as a standard for conducting steam-boiler trials. The revised code of the society defines it as follows: "The unit of commercial horsepower developed by a boiler shall be taken as $34\frac{1}{2}$ units of evaporation per hour—that is, $34\frac{1}{2}$ pounds of water evaporated per hour from a feed-water temperature of 212° F. into dry steam of the same temperature. This standard is equivalent to 33,137 British thermal units per hour. It is also practically equivalent to an evaporation of 30 pounds of water from a feed-water temperature of 100° F. into steam at 70 pounds gage pressure." The unit of evaporation is thus equivalent to 965.7 British thermal units.

Capacity of boilers.—The measure of the capacity or rating of a boiler is variable, there being no standard. Under a proper method of rating the proposed rated capacity should be attained when using average coal, giving average attention to firing, and using only part of the available draft, yet obtaining good economy. To rate all boilers, whether of the water-tube or fire-tube type or a combination of the two, on the basis of 10 square feet of heating surface per boiler horsepower is becoming a general practice, as this method comes within the required conditions.

DETERMINATION OF TOTAL HEATING SURFACE.

The determination of the total heating surface with sufficient accuracy for ordinary purposes is not difficult. A short approximate method for any boiler is to figure the heating surface in the tubes and divide it by 0.85 for a return tubular boiler or by 0.90 for a water-tube boiler. In case the return tubular boiler has an arch over the top for gas passage, giving a so-called third return, it is necessary to add from 100 to 200 square feet to the result to obtain the total heating surface.

This short method may be proved by two examples, as follows:

(1) Take a return tubular boiler which is 18 feet long and 6 feet in diameter, with 72 4-inch tubes. According to Kent, the square feet per foot length for a 4-inch tube = 1.047; then—

$1.047 \times 18 \times 72 = 1{,}357$ square feet in tubes.

$3.1416 \times 6 \times 18 = 339$ square feet in shell.

$(3.1416 \times 9) - (72 \times 3.1416 \times 0.172) \times 2 = 44$ square feet in tube sheets.

Hence the total effective heating surface $= 1357 + \frac{339}{2} + 44 = 1570$; but $\frac{1{,}357}{1{,}570} = 0.863+$, hence approximately 85 per cent of the total effective heating surface of a return tubular boiler is in the tubes.

(2) Take a Heine water-tube boiler having 116 tubes $3\frac{1}{2}$ inches in diameter and 18 feet long and a 42-inch drum 21 feet 6 inches long. According to Kent, the square feet per foot length for a $3\frac{1}{2}$-inch tube = 0.916; then $0.916 \times 18 \times 116 = 1{,}912$ square feet in tubes. The approximate dimensions of the water legs are 6 feet 6 inches by 4 feet = 26 square feet; the tube area in water legs = 8 square feet; and the heating surface in water legs $= (26 \times 2) - (8 \times 2) = 36$ square feet. The effective heating surface in drum $= \frac{3.1416 \times 3.6 \times 21.5}{2} =$ 118 square feet. Thus, the total effective heating surface $=$ $1{,}912 + 36 + 118 = 2{,}066$ square feet; but $\frac{1{,}912}{2{,}066} = 0.925+$, hence approximately 92 per cent of the total effective heating surface of a Heine water-tube boiler is in the tubes. In other types of water-tube boilers the ratio was found to be lower; but 90 per cent may be assumed as a fair average ratio.

TESTS BY THE GEOLOGICAL SURVEY.

GENERAL STATEMENT.

During 1904 to 1906 coals from all parts of the United States were burned at the government fuel-testing plant at St. Louis, in furnaces which were in the main of the same design. Most of the tests[a]

[a] For descriptions of the plant and tests see Bull. U. S. Geol. Survey Nos. 261, 290, 323, and 332.

were made on a hand-fired furnace under a Heine water-tube boiler. The lower row of tubes of the boiler supported a tile roof for the furnace, giving the gases from the coal a travel of about 12 feet before coming into contact with the boiler surface. This furnace is more favorable to complete combustion than those installed in the average plant. A number of coals were burned in this furnace with little or no smoke, but many coals could not be burned without making smoke that would violate a reasonable city ordinance when the boiler was run at or above its rated capacity. Boilers having furnaces installed under less favorable conditions will give off more smoke.

In 1907 the steaming section of the St. Louis plant was moved to Norfolk, Va., where subsequent tests of this nature have been made. The plant at Norfolk was equipped with two furnaces—one fired by hand and the other by a mechanical stoker. Both were operated under Heine boilers.

In the course of the steaming tests at St. Louis and Norfolk some special smoke tests were made and the influence of various factors in smoke production was noted. As the tests were made as far as possible under standard conditions, with a minimum of variation in boiler-room labor, the results bring out the importance of other factors such as character of fuel and furnace design.

SUMMARY OF CONCLUSIONS.

A detailed discussion of these tests, with numerous tables, is presented on pages 139–167 of this volume. A brief summary of the general conclusions is as follows:

A well-designed and operated furnace will burn many coals without smoke up to a certain number of pounds per hour, the rate varying with different coals, depending on their chemical composition. If more than this amount is burned, the efficiency will decrease and smoke will be made, owing to the lack of furnace capacity to supply air and mix gases.

High volatile matter in the coal gives low efficiency, and vice versa. The highest efficiency was obtained when the furnace was run at low capacity. When the furnace was forced the efficiency decreased.

With a hand-fired furnace the best results were obtained when firing was done most frequently, with the smallest charge.

Small sizes of coal burned with less smoke than large sizes, but developed lower capacities.

Peat, lignite, and subbituminous coal burned readily in the type of tile-roofed furnace used and developed the rated capacity with practically no smoke.

Coals which smoked badly gave efficiencies 3 to 5 per cent lower than the coals burning with little smoke.

Briquets were found to be an excellent form for using slack coal in a hand-fired plant. They can be burned at a fairly rapid rate

of combustion with good efficiency and with practically no smoke. High-volatile coals when briquetted are perhaps as valuable as low-volatile coals when not briquetted.

A comparison of tests on the same coal washed and unwashed showed that under the same conditions the washed coal burned much more rapidly than the raw coal, thus developing high rated capacities. In the average hand-fired furnace washed coal burns with lower efficiency and makes more smoke than raw coal. However, washed coal offers a means of running at high capacity, with good efficiency, in a well-designed furnace.

Forced draft did not burn coal any more efficiently than natural draft. It supplied enough air for high rates of combustion, but as the capacity of the boiler increased the efficiency decreased and the percentage of black smoke increased.

Most coals that do not clinker excessively can be burned with 1 to 5 per cent greater efficiency and with a smaller percentage of black smoke on a rocking grate than on a flat grate.

Air admitted freely at firing and for a short period thereafter increases efficiency and reduces smoke.

As the CO in the flue gas increases the black smoke increases; the percentage of CO in the flue gas is therefore, in general, a good guide to efficient operation. However, owing to the difficulty of determining this factor, combustion can not be regulated by it.

The simplest guide to good operation is pounds of coal burned per square foot of grate surface per hour.

REPRESENTATIVE BOILER PLANTS BURNING COAL WITHOUT SMOKE.

GENERAL STATEMENT.

Bulletin 334, the preliminary report on smokeless combustion, takes up information collected and conclusions reached while assembling the data summarized in the present report and sets forth many facts of general interest that are not discussed in the following pages. This paper deals especially with the equipment of particular boiler plants which were found to be burning coal without smoke, and with the essentials of good furnace design. A brief summary of the general conclusions is presented on pages 171–172. The details on which these conclusions are based are set forth in the following pages.

For the sake of clearness the important features of the equipment of the boiler plants visited are stated in tabular form.

Although there were very few plants at which all the items covered by the tables could be ascertained, the more essential details—those bearing directly on the subject of smoke prevention—were obtained at nearly every plant. The density of the smoke is stated on a percentage basis, 0 meaning a clean stack and 100 per cent meaning dense black smoke.

In the tables the furnace dimensions are checked by letters from A to H, which refer to the dimensions indicated by the corresponding letters on the illustrations showing typical installations of furnaces under boilers of various types. These illustrations are intended to show especially the average and the minimum travel of the gases from the fire to the first cooling surface in the boiler, the height of the furnace, and the length of the coking arch.

In the illustrations some makes of boilers appear more frequently than others. This does not imply any preference for certain models. Boilers of widely differing patterns have shown equal efficiency in steaming trials, and it is coming to be a general belief that among the types of boilers ordinarily used at power plants peculiarities of tube arrangement count for less than proper furnace design. This report of what has been done to effect smokeless combustion emphasizes the importance of furnace design and management and makes no comparisons between boilers. The illustrations show details of furnace construction and the importance of certain features.

For convenience of treatment the following order is adopted in discussing the equipment of the various plants:

Mechanical stoker plants.
- (*a*) Overfeed stokers.
  1. Chain grates.
  2. Front feed.
  3. Side feed.
- (*b*) Underfeed stokers.

Hand-fired plants.
- (*a*) Furnaces under water-tube boilers.
- (*b*) Furnaces under return tubular boilers.
  1. Down-draft furnaces.
  2. Furnaces using steam jets.
  3. Furnaces with miscellaneous equipment.

PLANTS WITH MECHANICAL STOKERS.

The use of mechanical devices for firing coal reduces labor in the boiler room, but the main object of mechanical stoking is to feed a steady, regulated supply of coal and air to the furnace. The advantages of feeding a fire steadily were seen in the early days of steam engineering, but defects in design or faulty installation and management kept mechanical stokers from coming into general use. Within the last decade, however, their use has greatly increased. They are of two general types—overfeed and underfeed.

OVERFEED STOKERS.

CHAIN GRATES.

GENERAL DISCUSSION.

The earliest mechanical stoker was of the treadmill type, so called because the arrangement of the grate bars as a traveling belt resembled the apron of a treadmill. It was patented in England as far back as 1841. Improved in details of construction, this type, under the name chain grate, has come into extensive use in this country. The coal is fed from a hopper, which extends the entire width of the grate

and has a plate at the back for regulating the depth of the bed of coal, to a continuously revolving grate, the top of which is made to move from front to rear by power applied to the front or rear sprocket shaft. As usually installed, the surface of the grate is horizontal, but occasionally chain grates are given a slight incline. Back of the hopper and extending over the whole width of the grate is a fire-brick arch. The length of this arch differs in plants equipped by different makers, but the present tendency is to lengthen the arch and to proportion its length and slope to the grade of coal to be used.

In operation, coal from the hopper begins to ignite as it passes under the arch and the grates carry the burning coal toward the bridge

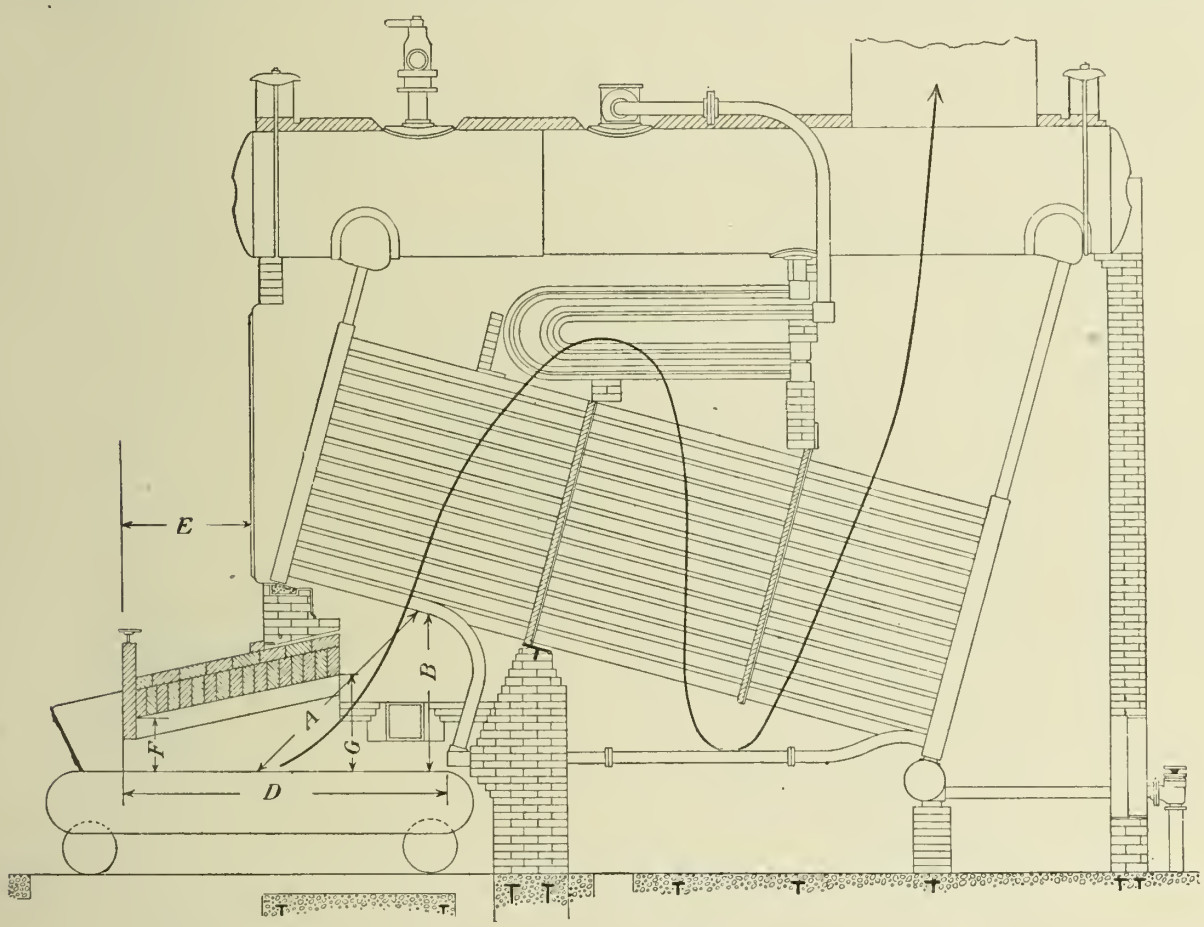


FIGURE 1.—Chain-grate stoker and Babcock & Wilcox boiler with uptake in rear.

wall at a rate which permits complete combustion before the chain passes the rear sprocket and the refuse falls into the ash pit below.

The majority of the stokers of this type are particularly adapted to a free-burning coal high in volatile matter, such as is mined in the central and western fields, and give less satisfaction with the higher fixed carbon coking coals of the Appalachian field. As they can burn the poorest grades of noncoking coal with complete combustion, they offer a valuable means of producing cheap power. At all the plants visited where these stokers were in use small coal was burned.

As has been said, the chief difference at present among chain grates as put in by the various makers is in the length of the fire-brick arch.

In many water-tube boilers this arch is made short, and the gases of combustion are led to the tubes by the shortest path. A furnace and boiler with stoker thus set are shown in figure 1. In this setting

the distance of travel for the gases from the grates to the tube heating surface, indicated by the line *B*, is reduced to a minimum and the average distance from the fire to the first cooling surface encountered (*A*) approaches a minimum.

This type of installation is common in the Middle West, where a higher proportion of chain grates is in use than in any other section of the United States, but the short arch and the brief travel of the gases to the first tube heating surface are features unfavorable to smokeless combustion.

A water-tube boiler of another make with furnace fed by chain grates is shown in figure 2.

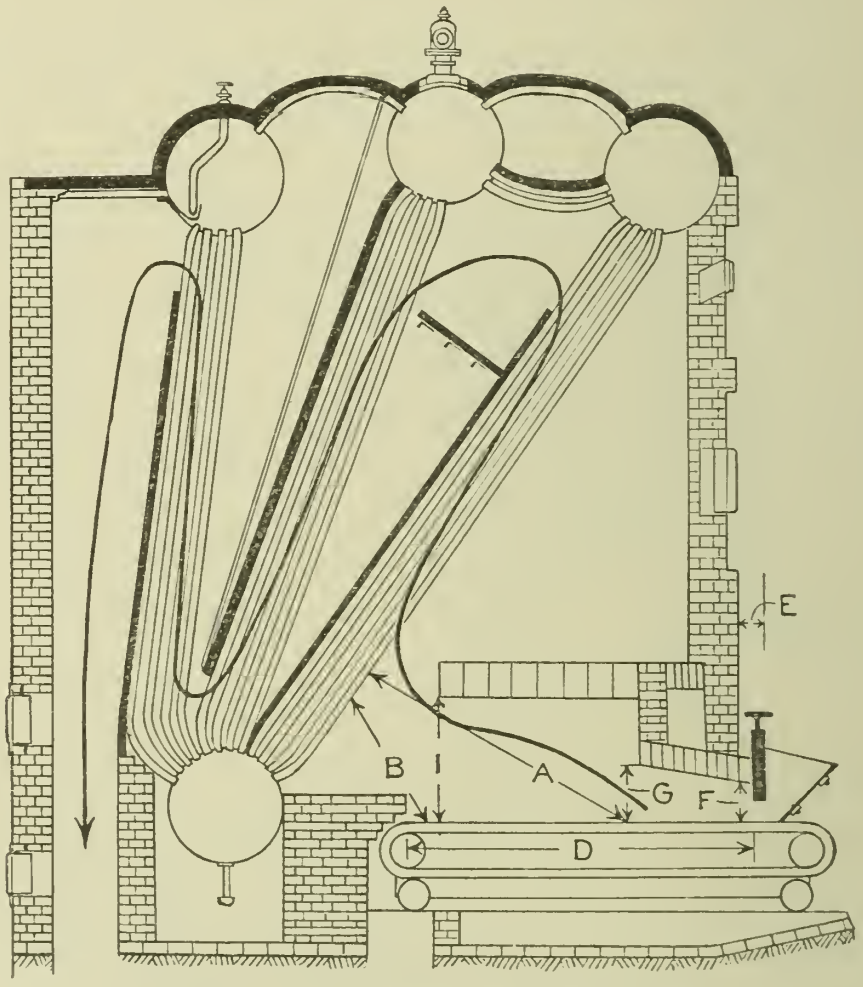


FIGURE 2.—Chain-grate stoker and Stirling boiler.

A method of setting designed to lengthen the travel of the combustible gases from the bed of coal and allow them to mix and be completely burned before entering the boiler is shown by figure 3. Here the type of boiler illustrated by figure 1 is baffled so that the uptake is in front; the fire-brick arch over the grates is no longer than in the other furnace, but it is supplemented by the bottom baffling made of C tile supported by the water tubes, so that the least distance from grates to tube heating surface is three times as long as in the mounting shown in figure 1. The bottom baffling,

though it can not, on account of its construction, become as hot as the ignition arch, has slight chilling effect, and there is ample opportunity for complete combustion before the gases reach the first cooling surface.

Comparatively few chain-grate stokers were found under tubular boilers. An example of the usual setting is given in figure 4. Here, while the ignition arch is short and the shell of the boiler has a cooling effect, the average distance from the grates to the beginning of the tube heating surface is so long that smokeless combustion can be

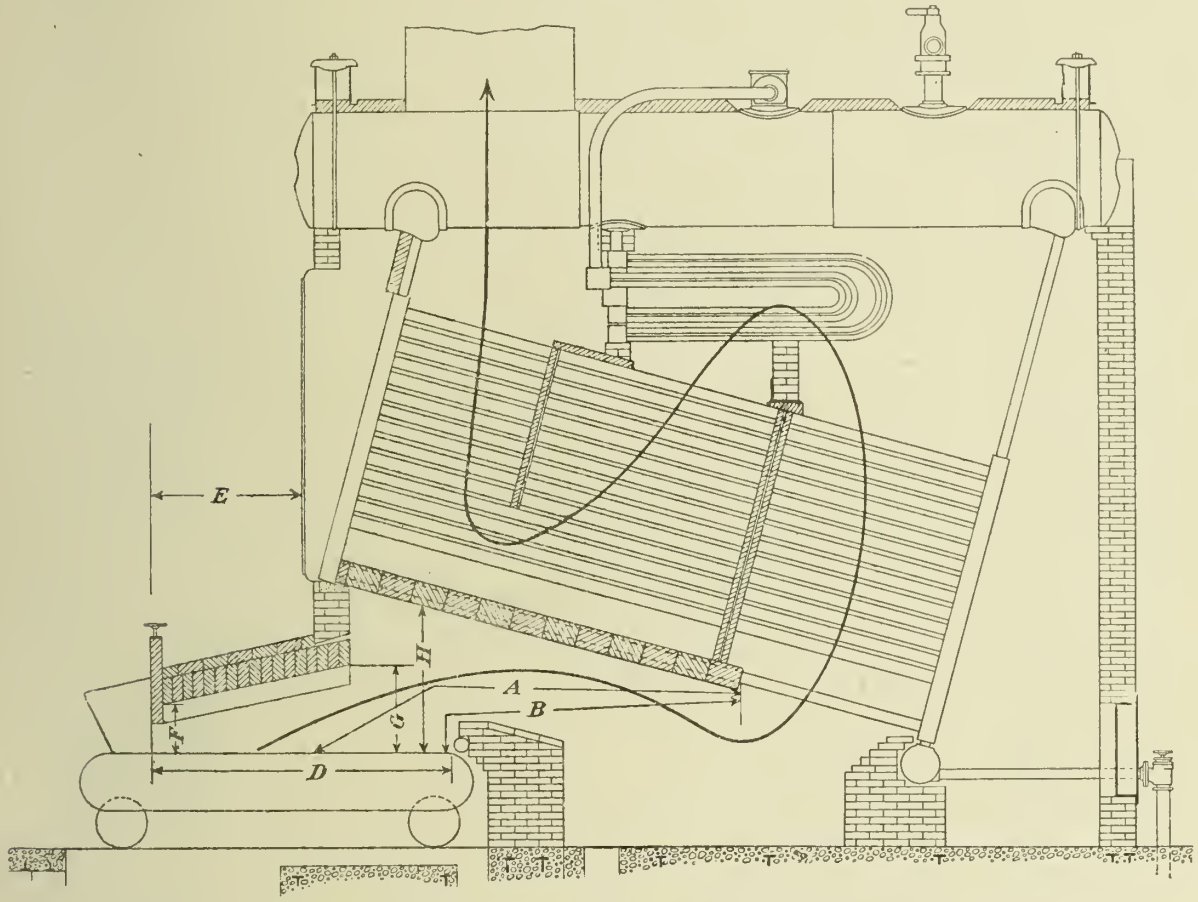


FIGURE 3.—Chain-grate stoker and Babcock & Wilcox boiler with uptake in front.

obtained with ordinary care in operation. In the journey from the grate to the rear of the boiler the cooling effect of the boiler shell, though not negligible, is much less than it is often thought to be, inasmuch as the area exposed is not more than that of eight or nine tubes.

DETAILED DESCRIPTION OF PLANTS.

In the course of the field investigation 57 plants, ranging from 300 to 9,600 rated boiler horsepower, at which chain grates were installed were visited. The detailed information collected regarding these plants is presented in Table 5 (pp. 19–32), but some of the more important facts to be gained from a study of that table are summarized here.

The coals used, all small sizes, came from five different States and the average depth of fire in burning them ranged from 4.5 to 6 inches.

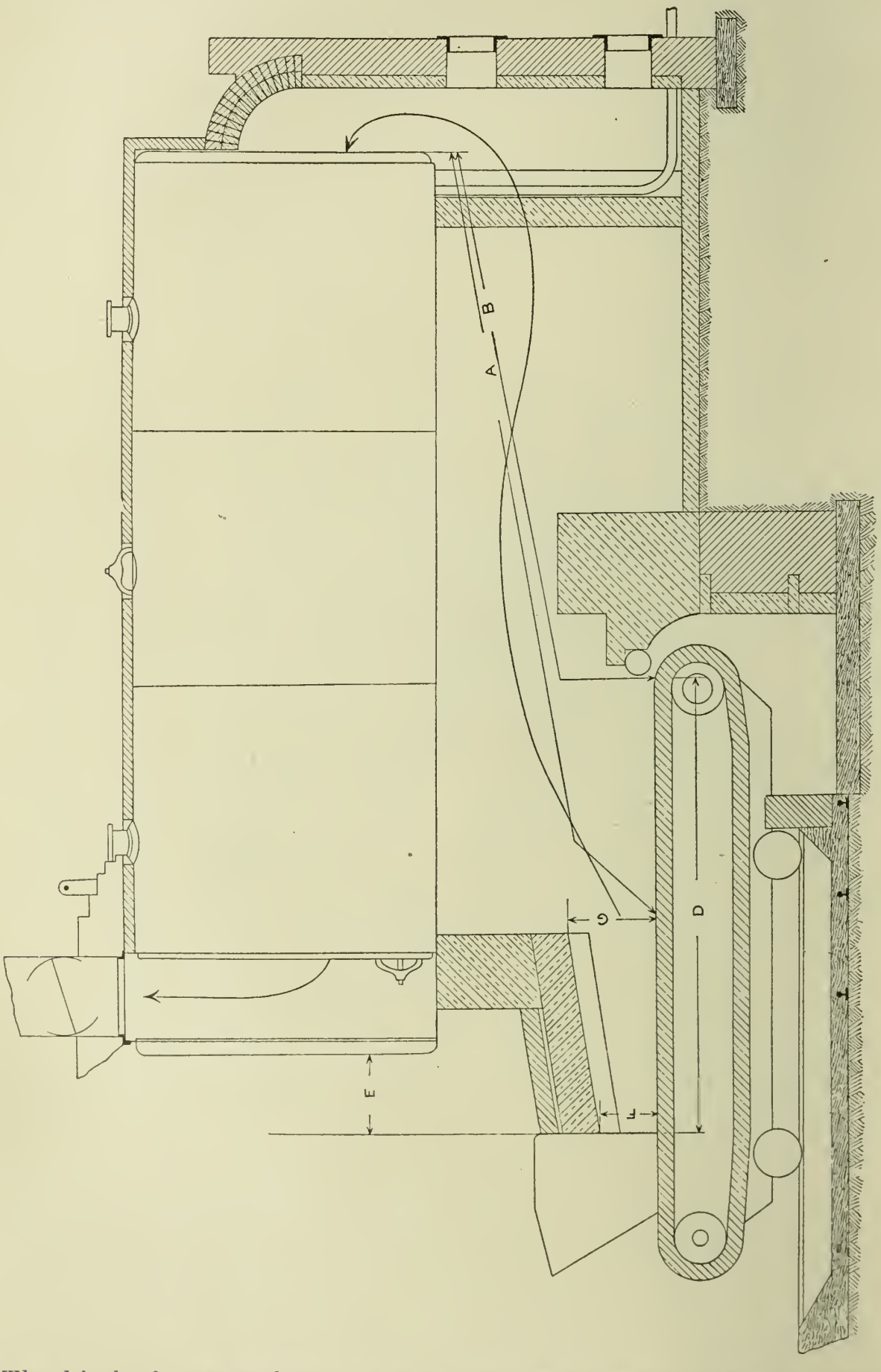


FIGURE 4.—Chain-grate stoker and return tubular boiler.

The kind of coal and the depth of fire are given in Table 1, which incidentally shows that the chain-grate stoker has been found to work remarkably well with Illinois coals.

TABLE 1.—*Kind of coal and depth of fire at plants with chain grates.*

Kind of coal.	Number of plants.[a]	Average depth of fire.	Kind of coal.	Number of plants.[a]	Average depth of fire.
		Inches.			*Inches.*
Illinois	21	5	Ohio	6	5
Indiana	8	5	Pennsylvania	6	4.5
Kentucky	8	4	Miscellaneous	10	6

[a] Two plants burned both Indiana and Illinois coal.

Forty of these plants maintained uniform loads; the remainder had to carry variable loads. At 18 per cent of the plants the stokers were under boiler units of 200 horsepower or less and at 69 per cent they were under units of 300 horsepower or less. The average boiler horsepower developed, the boiler being rated on 10 square feet of heating surface per horsepower, ranged from 23 to 158, the average being 93. The ratio of square feet of heating surface to square feet of grate surface varied from 33 to 1 to 88 to 1, the average ratio being 50 to 1.

The height of the ignition arch at the front of the furnace ranged from 0.9 to 1.1 feet, and the height above the grate at the rear of the arch from 1.3 to 2.2 feet. In 16 plants out of 46 the forward ends of the stokers were some distance in front of the boiler. The average height of the ignition arches above the grates is given in Table 2.

TABLE 2.—*Average height of arch at front and rear at plants with chain grates.*

Type of boiler.	At front of furnace.		At rear of furnace.	
	Average height of arch.	Number of plants at which measured.	Average height of arch.	Number of plants at which measured.
	Feet.		*Feet.*	
Aultman & Taylor	1.1	6	1.7	6
Babcock & Wilcox	1.1	13	1.5	13
Heine	1.1	6	1.6	5
Stirling	.9	16	1.5	14
Miscellaneous water-tube	1	3	1.3	3
Return tubular	1.1	5	2.2	6

The coal as received burned per square foot of grate per hour of average heavy load ranged from 11.4 to 39 pounds, the average being 23.3 pounds.

Table 3 presents in more impressive form some of the particulars recapitulated above. It was compiled to show that with chain-grate stokers installed under 10 types of boilers (five different makes of water-tube boilers are included under "Miscellaneous") which were run at about their full capacity, at no plant was there any serious emission of smoke, combustion being practically smokeless. As

bearing on the proper length of travel of the burning gases for coals from different States, the least and average distances from grates to tube heating surface are given.

TABLE 3.—*Summary of various observations at plants with chain grates.*

Type of boiler.	Kind of coal.	Number of plants.	Furnace draft.	Coal burned per square foot of grate surface per hour, average heavy load.	Percentage of rated boiler horsepower developed, average heavy load.[a]	Distance from grates to tube heating surface.		Black smoke.
						Average.	Minimum.	
			Inch of water.	*Pounds.*		*Feet.*	*Feet.*	*Per ct.*
Aultman & Taylor.	Illinois, Ohio, and Pennsylvania.	7	0.23	19.4	83	5.2	3.2	4.4
Babcock & Wilcox.	Illinois, Kentucky, Ohio, and Pennsylvania.	12	.21	24.0	88	5.2	3.3	2.7
Heine	Illinois	7	.22	21.2	113	8.4	6.4	6.5
Stirling	Illinois, Indiana, Kentucky, and Ohio.	18	.19	23.5	94	7.0	4.9	5.4
Miscellaneous water-tube.	Indiana, Kentucky, and Pennsylvania.	5	.20	26.2	104	8.3	5.5	7.5
Return tubular	Illinois, Kentucky, Pennsylvania, and Indiana.	8	.15	24.9	108	19.0	14.7	2.8

[a] Boiler rated on 10 square feet of heating surface per horsepower.

The draft measurements at the plants with chain grates are summarized in Table 4.

TABLE 4.—*Summary of draft measurements at plants with chain grates.*

Type of boiler.	Measurement taken at—	Number of plants at which taken.	Average draft (inch of water).
Aultman & Taylor	Furnace	5	0.23
	Rear of boiler	6	.46
	Base of stack	3	.71
Babcock & Wilcox	Furnace	12	.21
	Rear of boiler	11	.34
	Base of stack	5	.57
Heine	Furnace	5	.22
	Rear of boiler	2	.58
	Base of stack	4	.77
Stirling	Furnace	18	.19
	Rear of boiler	17	.47
	Base of stack	7	.96
Miscellaneous water-tube	Furnace	6	.20
	Rear of boiler	4	.41
	Base of stack	2	.60
Return tubular	Furnace	8	.15
	Front-tube sheet	4	.43
	Base of stack	3	.81

Average furnace draft, 54 plants, 0.19 inch of water; range, 0.07 to 0.45 inch. Average draft at rear of boiler, 40 plants, 0.43 inch of water; range, 0.11 to 0.94 inch. Average draft at front tube sheet, 4 plants, 0.43 inch of water; range, 0.25 to 0.61 inch. Average draft at base of stack, 24 plants, 0.77 inch of water; range, 0.26 to 1.30 inch. These figures show approximate average drafts as follows: Furnace, 0.20 inch of water; rear of boiler, 0.45 inch; base of stack, 0.80 inch. These results give a drop in draft through the boiler of 0.25 inch of water and a drop from boiler to stack of 0.35 inch.

TABLE 5.—*Details of observations at plants with chain grates.*

No. of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
1	Illinois	Aultman & Taylor	700	Carterville	Illinois	No. 3		
2	Ohio	do	1,100	Pittsburg No. 8	Ohio	Slack	$2.00	6,188
3	do	do	1,000	Various coals		¾-inch screenings	1.50	10,950
4	do	do	825	Pittsburg No. 8	Ohio	Slack	2.15	6,000
5	do	do	500	Bessemer	Pennsylvania	do	1.80	9,000
6	Illinois	Green	600	Various coals		1¼-inch screenings	1.45	
7	do	Mansfield	600	do		do		
8	do	Green	1,440	Washed	Ladd, Ill	No. 5	1.55	
9	do	do	1,035		Carterville, Ill	Nos. 3 and 4 mixed	2.10	
10	Kentucky	do	500		Western Kentucky	Nut and slack		
11	do	do	655		do	do	1.58	
12	Ohio	Babcock & Wilcox	595	Gaylord	Belmont County, Ohio	¾-inch screenings	1.40	3,720
13	do	do	450		Eastern Ohio	Nut and slack	2.05–2.35	2,500
14	Pennsylvania	do	3,600	Second pool	Monongahela River, Pa	1¼-inch screenings		16,000
15	Ohio	do	2,184	Youghiogheny	Pennsylvania	Slack	1.75	23,360
16	do	Babcock & Wilcox; Green	1,200	Pittsburg	do	do	1.75	6,500
17	do	Babcock & Wilcox	500	Various coals		do	1.70	4,700
18	do	do	310	Morgan Run			1.60	2,500
19	do	do	300			Nut and slack	1.75	3,000
20	Illinois	Green	2,700		Indiana; Illinois	1¼-inch screenings	1.35	
21	do	McKenzie	2,075		Williamson and Marion counties, Ill.	No. 3 nut	2.75	
22	do	McKenzie bar	1,000	Washed	Carterville, Ill	No. 3		
23	do	Green	750	do	Illinois	No. 4	3.00	
24	Missouri	American	600	Carterville, washed	do	Pea	1.80	1,800
25	Illinois	Green	1,260			1¼-inch screenings	1.60	
26	do	do	1,800	Washed	Illinois	No. 4		
27	do	do	1,500		do	Nut and slack	2.30	
28	do	do	1,050		do	Screenings	1.20	
29	do	do	800		Indiana; Illinois	1¼-inch screenings	1.35	
30	do	do	800		Illinois	2-inch screenings		
31	do	do	608	Duquoin, Springfield	do	1¼-inch screenings	1.25	
32	do	do	600	Washed	Carterville, Ill	No. 4		
33	do	do	600	Duquoin; Springfield	Illinois	1¼-inch screenings	1.25	
34	do	do	400	Washed	Carterville, Ill	No. 2	2.65	
35	Indiana	do	1,520		Indiana	Slack		
36	do	do	675		do	do		
37	do	do	495		do	Nut and slack		
38	do	American	201		Southern Indiana	do		
39	Kentucky	Green	620		Western Kentucky	Pea and slack		

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
40	Kentucky	Green	300		Eastern Kentucky	Nut and slack		
41	Ohio	McKenzie	3,400	Cambridge	Ohio	Pea and slack	$1.80	110,000
42	do	Green	1,170	Pittsburg No. 8	do	Slack	1.75	9,600
43	Illinois	do	9,600	Various coals				
44	Indiana	Babcock & Wilcox	1,000	Linton No. 4	Indiana	Nut, pea, and slack		
45	Kentucky	Green	924		Western Kentucky	Pea and slack		
46	do	do	400		do	do		
47	do	do	350		do	do		
48	Ohio	Aultman & Taylor	1,000	Youghiogheny	Pennsylvania	Slack	1.70	19,200
49	Illinois	Mansfield	1,584	Various coals		Screenings	1.50	
50	do	Green	1,400	Washed	Marion County, Ill	No. 3		
51	Missouri	do	750	do	Collinsville, Ill	Nos. 2, 3, and 4	1.90	4,400
52	do	do	500	do	Carterville, Ill	No. 4	1.75	
53	Illinois	S. and S	300	do	do	do	2.75	
54	Indiana	Green	300		Indiana	Nut and slack	1.60	
55	Kentucky	do	600		Western Kentucky	Pea and slack		
56	New York	McKenzie	4,000	Youghiogheny	Pennsylvania	¾-inch screenings	2.10	55,000
57	Illinois	Green	400	Various coals		Screenings		

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Load.			Rating.								
	Requirement.	Nature.	Character.	Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds)
				Heavy.		Light.						
				Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
1	Power and light	Uniform	Cold storage	24	16	.....	.....	24.5	.....	71	71	5
2	Power, light, and heat	do	Office building	24	17	24	17	15	15	58	57	4.5
3	do	do	Factory	10	21	14	7	31	21	106	112	5
4	do	do	do	24	30	11	10.3	21	18.4	95	91	5
5	do	do	do	24	27	24	24	21.6	20.4	106	112	4
6	do	do	do	.....	.....	10	6	.....	20.5	80	80	5
7	do	Variable	Brewery	24	24	24	.....	14	.....	66	66	5
8	Power	Uniform	Shops	9	40	9	40	30.4	30.4	135	148	5
9	Power and heat	Variable	Department store	10	32	10	7	35.3	28.7	125	125	5
10	Power, light, and heat	Uniform	Office building	5	3.5	9	3.1	26	19.4	106	112	5
11	Light and heat	Variable	County jail	24	32	24	13	20.4	15.7	93	81	5
12	Power, light, and heat	Uniform	Factory	10	7.5	10	7	18.5	17.9	53	50	5
13	do	do	do	10	7.3	10	3.9	26.2	23.4	72	68	4.5
14	do	do	Offices and factory	24	50	24	39	13.7	12.2	58	58	4
15	Power	do	Waterworks	24	58.6	24	58.6	16.4	16.4	74	80	4.5
16	Power and light	do	Factory	10	13.3	10	12	18.4	17.5	73	74	4.5
17	Power, light, and heat	do	do	10	10.4	10	9.2	15.5	14.6	61	83	5
18	do	do	do	24	18	10.5	4	31.6	29.8	105	108	4.5
19	Power and light	do	do	9	7.5	9	6	30	27	105	111	5
20	Power, light, and heat	Variable	Packing house	14	112	14	112	29.9	29.9	139	139	5
21	Power and light	Uniform	Department store	11	50	11	45	28	27	115	115	5
22	do	Variable	Refrigeration	24	25	24	20	21	19	83	83	5
23	Power and heat	Uniform	Factory and offices	8.5	20	8.5	16	21	20	130	130	5
24	Power and light	do	Factory	12	6	12	4.5	18.5	16.3	71	67	5
25	Power, light, and heat	Variable	do	10	35	10	20	39	31	137	167	5
26	do	do	Shops and car heating	10	15	10	28	24	23	114	100	5
27	do	Uniform	Factory	24	110	24	110	29.2	29.2	123	123	5
28	do	Variable	do	11	25	11	22	34	32	130	130	5
29	do	do	Packing house	14	38	14	38	28.7	28.7	136	136	5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Load.			Rating.								
				Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
	Requirement.	Nature.	Character.	Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
30	Power, light, and heat	Uniform	Shops and car heating	24	50	24	20	19	17	104	104	5
31	do	do	Packing house	24	25	24	15	17	16	80	80	5
32	do	do	Office building	12	10	12	9	31	29	133	111	5
33	do	do	Packing house	24	25	24	15	16	15	70	70	5
34	do	do	Factory	12	10	12	6	19	15	80	80	5
35	do	Variable	Mill	10	60	10	45	32.2	28.2	158	158	5
36	do	do	Brewery	24	26	24	14	16.9	16.3	92	104	5
37	Light and heat	Uniform	Depot	24	18	12	2	22.6	16.4	92	91	5
38	Power, light, and heat	do	Mill	24	7.5	.....	.....	11.4	.....	62	62	5
39	Power and light	do	do	24	40	24	17	20.2	19.6	110	110	5
40	Power, light, and heat	Variable	Store building	11.5	3.5	20	5	16	14.5	81	81	5
41	Power and light	do	Commercial	24	116	24	116	.....	15	67	57	5
42	Power, light, and heat	Uniform	Mill	12	24	12	24	16.5	16.5	68	68	5
43	Power and light	Variable	Street railway	24	350	24	210	.....	20.8	.....	88	5
44	Power, light, and heat	do	Factory	10	22	10	18	30	27.3	106	117	5
45	do	do	do	24	65	24	58	26.5	25.1	145	120	5
46	do	Uniform	Mill	24	23	24	23	21.3	21.3	96	96	5
47	do	Variable	Factory	24	25	24	22	28.9	27.1	.....	119	5
48	do	Uniform	Shops	24	48	24	56	31.7	29.8	105	107	5
49	do	do	Pumping station	24	35	24	25	28	24	111	111	5
50	Power and light	do	Office building	.....	.....	10	14	21	21	90	80	5
51	do	do	Refrigeration	24	30	24	12	15.4	12.3	73	67	5
52	do	do	Factory	10	16.5	10	13.5	30.6	27.8	138	132	5
53	Power, light, and heat	do	Laundry	11.5	4.5	11.5	4	22	20.7	98	107	5
54	do	do	School building	20	7	12	4	19.4	19	143	93	5
55	Power and light	do	Ice plant	24	29.5	24	14.2	17.1	16.9	77	82	5
56	Power	do	Waterworks	24	151	24	151	24	24	80	93	4.5
57	do	do	Foundry and ironworks	.....	.....	10	11	.....	23.3	110	147	5

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Thickness of fire (inches).	Boilers.									
		Type.	Size.	Number installed.	Number used to carry—		Builder's rated horsepower.	Horsepower, boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage (pounds).
					Average heavy load.	Average light load.					
1	3	Aultman & Taylor water-tube..	168 4″ tubes; 2 48″ x 20⅛′ drums	2	1	1	350	350	3,500	0	140
2	4.5	.....do		4	2	2	400 150	394 151	3,935 1,510	0	150
3	4–4.5	.....do	126 4″ x 18′ tubes	4	3	2	250	264	2,640	0	110
4	3–4	.....do	126 4″ x 18′ tubes	3	2	2	275	264	2,640	0	120
5	4	.....do	126 4″ x 18′ tubes	2	2	2	250	264	2,640	.....	140
6	6–7	.....do	144 4″ x 18′ tubes, 2 36″ x 20.2′ drums	2	1	1	300	300	3,000	0	120
7	4–5	.....do	2 36″ drums	2	2	1	300	300	3,000	0	120
8	6	Babcock & Wilcox water-tube..	126 4″ x 18′ tubes, 2 36″ drums	6	5	5	240	264	2,640	0	140
9	4–10	.....do	162 4″ tubes, 3 36″ x 20⅓′ drums	3	3	1	345	345	3,450	0	80–90
10	3.5–4	.....do	117 4″ x 18′ tubes, 2 35″ x 21′ drums	2	1	1	250	264	2,640	0	105
11	3–5	Babcock & Wilcox; Henry Vogt	Babcock & Wilcox, 63 4″ x 18′ tubes; 1 drum	4	4	3	135 250	125 200	1,250 2,000	0	100–110
12	4–4.5	Babcock & Wilcox water-tube..	1–126 4″ x 18′ tubes, 2–72 4″ x 18′ drums	3	3	3	165 265	150 264	1,500 2,640	0	160
13	4–8	.....do	72 4″ x 18′ tubes	3	3	2	150	159	1,585	0	125
14	4–6	.....do	140 4″ x 18′ tubes	12	6	6	300	300	3,000	0	165
15	4–5	.....do	140 4″ x 18′ tubes	8	5	5	273	293	2,930	409	150
16	4–5	Babcock & Wilcox; Stirling water-tube.	192 4″ x 18′ tubes	3	2	2	400	400 410	4,000 4,100	0	130
17	3	Babcock & Wilcox water-tube..	142 4″ x 18′ tubes	2	2	2	250	298	2,980	0	140
18	4–8	.....do	72 4″ x 18′ tubes	2	2	1	155	159	1,585	0	135
19	3–5	.....do	72 4″ x 18′ tubes	2	2	2	150	159	1,585	0	150
20	6–8	Heine; Stirling water-tube		8	7	7	300 350 400	300 350 400	3,000 3,500 4,000	0	140
21	3–6	Heine water-tube		5	4	4	375 500 350	375 500 350	3,750 5,000 3,500	0	150
22	5–7	.....do	138 3½″ x 18′ tubes, 1 48″ x 20¾′ drum	4	2	2	250	250	2,500	0	85–90
23	4	Mohr and Heine water-tube....	Mohr, 140 3½″ x 18′ tubes; Heine, 138 3½″ x 18′ tubes.	3	3	2	250	250	2,500	0	80
24	4	Heine water-tube	138 3½″ x 20′ tubes	2	1	1	300	281	2,810	0	120
25	6	.....do	278 3½″ x 18′ tubes, 2 42″ drums	3	2	2	420	510	5,100	0	150–160
26	4–5	Stirling water-tube	223 3¼″ tubes, 3 42″ x 10 7/16′ drums	6	2	4	300	264	2,640	.....	160
27	6.5	.....do	192 3¼″ tubes, 3 42″ x 10′ drums	6	5	5	300	300	3,000	0	150

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Thickness of fire (inches).	Boilers. Type.	Size.	Number installed.	Number used to carry— Average heavy load.	Average light load.	Builder's rated horsepower.	Horsepower, boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage (pounds).
28	4	Stirling water-tube	340 3¼″ x 17½′ tubes, 3 42″ x 13′ drums	3	2	2	350	350	3,500	.....	155
29	6–8	.....do	.....	2	2	2	400	400	4,000	0	140
30	3	.....do	207 3¼″ tubes, 3 33″ x 10¾′ drums	4	4	2	200	200	2,000	0	100
31	4–6	.....do	272 3¼″ tubes, 3 36″ x 13¼′ drums	2	2	1	304	304	3,040	0	150
32	3–3.5	.....do	209 3¼″ tubes, 3 42″ x 11 3/10′ drums	2	1	1	300	250	2,500	0	80–100
33	4–6	.....do	181 3¼″ tubes, 3 36″ x 9¾′ drums	3	3	2	200	200	2,000	0	150
34	3–5	.....do	243 3¼″ tubes, 3 42″ x 13′ drums	1	1	1	400	400	4,000	0	100
35	4–4.5	.....do	.....	5	5	5	300 / 320	300 / 320	3,000 / 3,200	0	150
36	4	.....do	162 3½″ tubes, 3 33″ drums	3	2	1; 2	225	235	2,350	0	120–125
37	4.5	.....do	.....	3	2	1	165	164	1,640	0	125
38	5.5	.....do	192 3¼″ tubes, 3 33″ drums	1	1	1	201	201	2,010	0	115
39	3.5–4	.....do	.....	2	2	1	310	310	3,100	0	150
40	4.5	.....do	.....	2	1	1	150	150	1,500	0	150
41	4.5	Heine and Stirling water-tube	.....	8	8	8	500 / 350	375 / 345	3,750 / 3,450	0	150
42	4.5–5	Stirling water-tube	.....	4	4	4	327 / 258	328 / 259	3,277 / 2,587	0	160
43	7	.....do	240 3¼″ tubes, 3 40″ x 10′ drums	24	Variable.	Variable.	400	.....	.....	0	150
44	3–5	Cahall vertical water-tube	108 4″ x 22′ tubes	4	3	3	250	276	2,760	0	115
45	3	Erie water-tube	.....	3	3	3	300	250	2,500	0	120–130
46	3.5–4	Henry Vogt water-tube	.....	1	1	1	400	400	4,000	0	150
47	3	.....do	.....	1	1	1	350	.....	.....	0	120–130
48	4	Cahall vertical water-tube	.....	4	3	4	250	254	2,536	.....	150
49	8	Cahall horizontal water-tube	126 4″ x 18′ tubes, 2 36″ x 23 3/16′ drums	6	*a* 2	2	264	264	2,640	0	185
50	5–6	Sederholm return tubular	220 3″–87″ x 16′ tubes, 4 30″ x 12′ drums	4	.....	2	350	298	2,975	0	150
51	6	Bronson special fire-tube	102 3½″–72″ x 18′ tubes, 16 4″ water tubes	3	3	2	250	228	2,280	0	150
52	4	.....do	72″ x 20′–84 4″ tubes, 16 4″ water tubes	2	2	2	250	240	2,400	0	125
53	4–6	Return tubular	72″ x 18′, 72 4″ tubes	2	1	1	150	159	1,585	0	125
54	4–5	.....do	72″ x 18′, 27 6″ tubes	2	1	1	150	98	975	0	65–70
55	3.5	.....do	72″ x 18′, 72 4″ tubes	4	4	2	150	159	1,590	0	100
56	4	Return tubular and Bronson special fire-tube.	10 84″ x 18′, 176 3″, 6 90″ x 18′, 184 3″, and 13 4″.	16	12	12	250	275 / 311	2,750 / 3,110	0	130
57	7	Return tubular	72″ x 16′, 70 4″ tubes	4	.....	3	100	133	1,325	0	100

a Usually.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Furnaces.										
	Number.	Kind.	Grate area per boiler (square feet).	Dimensions (feet).							
				Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance from grates to coking arch.		Height of arch at rear of furnace (H).
				Average (A).	Minimum (B).				At front of furnace (F).	At rear of furnace (G).	
1	2	Plain	54.4	.....	.....	6.4	8.5	0	.....	.....	.....
2	4	.....do	67, 28	5.5	2.5	[a]8, 4.0	[a]8.4, 7	0	1.2	1.5	.....
3	4	.....do	45.5	4.0	2.5	6.0	7.7	0	1.25	1.5	.....
4	3	.....do	59.5	6.0	4.0	7.0	8.5	0	.9	1.5	.....
5	2	.....do	52	4.5	2.5	6.5	8.0	0	1.0	1.75	.....
6	2	.....do	58.5	6.0	4.3	6.5	9.0	3.0	.09	2.6	.....
7	2	.....do	72, 25	.....	.....	8.5	8.5	0	1.2	1.2	.....
8	6	.....do	58.5	4.2	3.3	6.5	9.0	3.0	.9	1.5	.....
9	3	.....do	63	6.5	4.0	7.0	9.0	0	1.2	1.2	.....
10	2	.....do	54	5.25	3.8	6.0	9.0	2.25	.9	1.6	.....
11	4	.....do	31.5, 36	[b]5.1, ——	[b]3.75, ——	[b]3.5, 4	9.0	[b]2.0, ——	[b].8, ——	[b]1.75, ——	.....
12	3	.....do	18, 45	5.0	2.5	[c]3.0, 7.5	6.0	0	1.25	1.5	.....
13	3	.....do	18, 19.8	4.5	3.0	3.0	[c]6.0, 6.75	0	1.25	1.5	.....
14	12	.....do	50.4	4.0	3.5	6.5	7.75	0	1.8	1.8	.....
15	8	.....do	59.4	6.0	3.5	6.4	9.25	0	1.25	1.9	.....
16	3	.....do	63.8, 81	[b]6, 8	3.5	[b]7.5, 9.0	[b]8.5, 9.0	0	[b]1.25, 75	[b]1.5, 1.25	.....
17	2	.....do	67.3	6.0	3.5	8.4	8.0	0	.9	1.3	.....
18	2	.....do	28, 25.3	5.5, 4.5	3.0, 2.0	3.5	8.0, 7.25	0	.4	1.6	.....
19	2	.....do	28	5.0	3.5	4.0	7.0	0	1.3	1.6	.....
20	10	.....do	72, 76.5, 94.5	[c]6.7, 4.3, 6.8	[c]4.0, 3.3, 4.1	[c]8.0, 8.5, 5.25	9.0	[c]0.8, 1.0, 0	.9	1.4	[c]3.6, —, 3.6
21	5	Tile roof	88, 93.5, 71.5	18.0	14.0	8.0, 8.5, 6.5	11.0	4.5	1.3	1.3	4.3
22	4	Partial tile roof	50	5.3	4.0	6.0	8.3	0	1.7	2.2	.....
23	3	Plain	76.5, 72	4.0, 16.0	3.25, 13.5	8.5, 8.0	9.0	2.3, ——	.8	1.5	.....
24	2	Tile roof	54	11.5	7.0	6.0	9.0	0	.....	.....	.....
25	3	.....do	90	4.3	3.6	10.0	9.0	2.25	.9	1.5	.....
26	6	Plain	63	8.7	6.0	7.0	9.0	1.9	1.0	1.5	4.25
27	5	.....do	63	7.3	5.6	7.0	9.0	0	.9	1.3	4.8
28	3	.....do	67.5	7.3	5.0	7.5	9.0	0	.9	1.5	5.0
29	2	.....do	94.5	.....	.....	5.25	9.0	.....	.....	.....	.....
30	4	.....do	54	6.5	4.5	6.0	9.0	0	.9	1.4	.....
31	2	.....do	67.5	6.7	4.5	7.5	9.0	.8	.9	1.4	.....

[a] First dimension applies to large boiler.

[b] First dimension applies to Babcock & Wilcox boiler.

[c] First dimension applies to small boiler.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Furnaces.										
	Number.	Kind.	Grate area per boiler (square feet).	Dimensions (feet).							
				Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance from grates to coking arch.		Height of arch at rear of furnace (H).
				Average (A).	Minimum (B).				At front of furnace (F).	At rear of furnace (G).	
32	2	Plain	54	6.8	4.3	6.0	9.0	0	1.0	1.5	4.6
33	3	.....do	45	6.7	4.7	5.0	9.0	.7	.9	1.4	4.9
34	1	.....do	90	8.2	5.5	10.0	9.0	0	.9	1.5	5.0
35	5	.....do	74.4	6.8	5.8	8.5	8.75	.75	.9	1.5	4.4
36	3	.....do	68.9	6.25	4.6	7.7	9.0	0	.9	1.5	3.6
37	3	.....do	33.2	6.0	4.4	4.0	8.3	0	.9	1.5	4.7
38	1	.....do	56	6.5	4.5	6.2	9.0	0	.....	.....	.....
39	2	.....do	74.3	6.0	4.2	8.25	9.0	0	.9	1.5	3.6
40	2	.....do	39.1	6.0	6.0	4.5	8.7	0	.8	1.6	4.2
41	8	.....do	81	[a] 3.0, 7.5	[a] 2.5, 4.5	9.0	9.0	0	1.0	1.5	—, 3.5
42	4	.....do	67.5, 54	8.5	4.0	[b] 7.5, 6.0	9.0	0	.9	1.5	3.8
43	24	.....do	84	8.0	5.7	9.3	9.0	0	.9	1.5	4.9
44	4	Dutch oven	49	10.0	6.0	6.3	7.75	10.5	.....	.....	.....
45	3	Plain	68	4.1	3.9	8.0	8.5	2.0	.9	1.6	.....
46	1	.....do	90	.....	.....	10.0	9.0	0	.....	.....	.....
47	1	.....do	72	.....	.....	.....	.....	.....	.....	.....	.....
48	4	Dutch oven	42	10.5	6.5	6.5	6.5	11.0	.7	1.0	5.2
49	6	.....do	51.6	8.5	5.5	6.4	8.0	4.0	1.3	1.3	3.6
50	4	Plain	67.5	17.5	13.0	7.5	9.0	0	1.0	1.75	.....
51	3	Tile roof	54	7.5	3.5	6.0	9.0	0	.....	.....	.....
52	2	.....do	54	6.5	2.5	6.0	9.0	0	.....	.....	.....
53	2	Plain	36	17.0	14.0	6.0	6.0	0	1.2	1.2	.....
54	2	.....do	36	5.0	4.1	4.0	9.0	0	.9	1.8	.....
55	4	.....do	36	18.0	13.5	4.0	9.0	0	.....	.....	.....
56	16	Plain and tile roof	42	[c] 21, 22	[c] 16, 17	6.0	7.0	0	1.5	[c] 2.3, 3.7	.....
57	4	Plain	31.5	18.5	14.5	3.5	9.0	1.3	1.1	2.7	.....

[a] First dimension applies to Heine boiler.

[b] First dimension applies to large boiler.

[c] First dimension applies to return tubular boiler.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Draft.							Smoke records.						
	Kind.	Readings (inches of water).					Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for 1 hour (minutes).			Average percentage of black smoke from observations.	Load during observations.
		Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
1	Chimney	0.26	0.40–0.48		0.82		Damper open, thin fire	4	225	0	2	34	8.2	Heavy.
2	do	.23–.27	.45–.73			0.85		1	60	0	0	55	1.7	Average.
3	do	.13–.15	.25			.60	Dampers open	1	60	0	0	43	6.3	Light.
4	do	.12–.23	.19–.30				Draft varied by thickness of fire.	1	600	0	0	60	0	Average.
5	do	.25–.27	.54–.63			.67		1	60	0	2	36	8.0	Do.
6	do	.30	.48–.58		.73		Dampers open; rear 2½′ of grate bare.	1	60	0	0	20	7.4	Light.
7	do		.55				Damper open; rear half of grate bare.	1	60	0	0	12	14.1	Heavy.
8	do	.15–.33	.35–.48		.47–.62		Dampers open	1	75	0	0		33.3	Average.
9	do	.40	.75		1.30		Dampers partly closed; thin fire.	1	60	0	0	60	0	Light.
10	do	.13	.24		.45		Dampers open; thin fire	1	60	0	0	37	9.8	Do.
11	do	.03–.11	.08–.14		.23		do	1	50	0	0	30	9.6	Do.
12	do	.09–.17	.14–.18			.32		1	600	0	0	58	.5	Do.
13	do	.18–.30	.25–.36				Damper open	1	60	0	0	40	1.7	Do.
14	do	.10–.20	.16–.33		.80			2	120	0	0	60	0	Do.
15	do	.18–.36			.36–.78	.97	Damper open	2	120	0	0	54	2.4	Average.
16	Induced	.19–.70	.45–1.10				Fan on full blast	1	60	0	0	58	.7	Light.
17	Chimney	.06–.07	.12–.15			.60	Damper partly closed	1	600	0	0	57	1.3	Average.
18	do	.12	.19–.21			.42		1	300	0	0	54	2.0	Heavy.
19	do	.17–.25	.28–.37			.52	Dampers open	1	600	0	0	54	3.0	Average.
20	Induced	.18–.32			Near stack 2.00		Dampers open; economizer in use.	1	60	0	0	60	0	Do.
21	Chimney	.21–.23	.74–.78				Damper open	1	61	0	3	27	10.2	Light.
22	do	.18			.60	.80	Dampers open	1	60	0	0	60	0	Heavy.
23	do	Very low.				.60	Dampers open; rear one-third of grates bare.	2	97	0	0	25	25.0	Average.
24	do	.24	.40			.63		1	60	0	0	48	5.7	Do.
25	do	.20	Combustion chamber, .31.		.92	1.04	Dampers one-half open; rear of grates bare.	1	60	0	0	45	3.8	Light.
26	do	.12	Lower, .40; upper, .50.		.68		Damper open; rear one-third of grates bare.	1	90	0	0	60	0	Average.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Draft.						Smoke records.						
	Kind.	Readings (inches of water).					Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for 1 hour (minutes).			Average percentage of black smoke from observations.	Load during observations.
		Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
27	Chimney..	0.18–0.32	Lower rear, 0.48–0.64.	.....	.....	.....	Dampers open.....	2	122	0	0	45	5.3	Average.
28	....do.....	.17– .18	Lower rear, .38– .41.	.....	.....	.84	Dampers open; rear of grates bare.	1	60	0	0	.....	.....	Do.
29	....do.....	.17– .18	Lower rear, 33– .38.	.....	.52	.....	Damper open.....	1	60	0	0	60	0	Do.
30	....do.....	.04– .17	Lower rear, .16– .40.	.....	.....	.68	Thin fire; running conditions	(a)	(b)	0	0	.....	.....	Light.
31	....do.....	.28, .29	Lower, .48; upper, .90.	.....	.....	.....	Dampers open.....	1	60	0	0	60	0	Average.
32	....do.....	.08– .10	Lower rear, .25	.....	.85	.....	Damper open; rear half of grate bare.	2	122	0	0	45	8.7	Do.
33	....do.....	.14– .17	Lower, .27– .28; upper, .48–.66	.....	.....	.....	Dampers open.....	1	60	0	0	53	2.8	Do.
34	....do.....	.11	Lower, .32; upper, .63.	.....	.72	.....	Damper open; rear one-third of grates bare.	2	120	0	0	51	3.0	Heavy.
35	....do.....	.23– .32	Lower rear, .58	.....	.....	1.12	Dampers open.....	1	75	0	2	(c)	0–3.3	Light.
36	Induced...	.09– .15	Lower rear, .31– .33.	.....	.....	.....	Dampers partly closed.....	2	45	0	0	60	0	Heavy.
37	Chimney..	.27	.56– .61	.....	.97	.....	Dampers open.....	2	120	0	0	51	4.1	Light.
38	....do.....	.36– .35	Lower rear, .56	.....	.....	.90	Damper open.....	1	35	0	0	56	1.7	Heavy.
39	....do.....	.11	Lower rear, .52	.....	.....	.78	.....do.....	1	80	0	0	60	0	Average.
40	....do.....	.13	.47	.....	.72	.....	Damper open; thin fire.....	1	43	0	0	21	9.1	Do.
41	....do.....	.18	.....	.....	.70	1.10	Dampers open.....	(a)	(b)	0	0	30	9.0	Do.
42	....do.....	.14– .23	Lower rear, .80–1.08.	.....	.....	1.30	.....do.....	1	600	0	0	53	3.3	Do.
43	....do.....	.19– .25	Lower rear, .65– .77.	.....	.34– .90	.....	.....do.....	1	60	0	0	21	11.7	Do.
44	....do.....	.31– .44	.....	.....	.....	.94	.....do.....	1	40	0	0	60	0	Light.
45	....do.....	.11– .14	.58– .67	.....	.....	.....	.....do.....	(a)	(b)	0	0	60	0	Average.
46	....do.....	.09	.36	.....	.70	.....	.....do.....	1	80	0	0	0	30.0	Do.
47	....do.....	.12	.30	.....	.....	.....	Damper open.....	(a)	(b)	0	0	.....	.....	Do.
48	....do.....	.17– .26	.....	.....	.....	26	.....do.....	1	600	0	0	60	0	Do.

49	....do.....	.25	.35	.....	.80	.....	Dampers open; rear one-third of grates bare.	1	60	0	0	60	0	Do.
50	....do.....	.10– .13	Combustion chamber,.14–.26	.....	1.20	.....	Rear one-third of grates bare.	7	419	0	0	53	.9	Light.
51	....do.....	.12	.....	0.52	.....	.....	Damper open.....	1	60	0	0	53	3.0	Heavy.
52	....do.....	.17	.....	.....	.86	.....	.....	1	60	0	0	57	1.0	Average.
53	....do.....	.10	.....	.25	.....	.55	Damper open.....	1	60	0	0	60	0	Do.
54	Induced...	.20– .30	.....	.45– .77	1.10–1.50	.....	Average running conditions.	2	60	0	0	60	0	Light.
55	Chimney..	.12– .13	.....	.....	.56	.....	Dampers open.....	2	140	0	0	60	0	Average.
56	Induced...	.10– .18	.....	.20– .45	.62	1.25	.....	1	60	0	0	58	.7	Do.
57	Chimney..	.18– .20	.....	.....	.55	.63	Dampers open.....	1	60	0	0	60	0	Light.

a Several.

b Various lengths.

c Variable.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Breeching.				Stack.			Ignition arch.		Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	Length (feet).	Style.	
1	5	.....	.....	0	125	a 5.4	23.0	4.5	Sprung..	Usually run with damper partly closed. Smokes considerably, 10 to 20 per cent black.
2	9	.....	.....	0	216	6.5	33.2	3.5	.....	
3	4	.....	.....	1	150	8.0	50.25	.....	.....	Coal runs from 10 to 15 per cent ash. Plant has to run with damper nearly wide open to keep from making smoke.
4	10	.....	.....	0	175	6.0	28.3	.....	.....	Range of draft obtained by taking readings on both thin and heavy fires. An air injector on each boiler consisting of ¾-inch steam jet passing through 2-inch pipe. When air injector is not in use, stack smoke varies from 20 to 40 per cent black.
5	10	.....	.....	1	125	a 5.0	19.6	3.5	.....	Coal as fired runs about 2 per cent moisture and 6 to 9 per cent ash. Smokes considerably, 10 to 20 per cent black.
6	6	4 x 7	Near stack.....	0	175	a 5.5	23.7	5.0	.....	Usually burns Illinois screenings. Smokes considerably, 10 per cent black.
7	0	.....	.....	0	135	a 8.0	50.25	3.0	Sprung..	When the draft is not reduced below 0.20 inch inside stack damper, stack smokes. 10 to 20 per cent black. Reducing draft below 0.20 inch gives bad stack.
8	28	9 x 5½	Near stack.....	0	185	8.0	50.25	.....	.....	Stack usually smokes, 20 to 30 per cent black.
9	22	6 x 12	.....do.....	0	275	8.0	50.25	6.5	Flat.....	Before present arch was installed ignition arch was 1.7 feet from grate at the rear and 3.5 feet long, and stack smoked badly at times.
10	16	.....	.....	1	116	a 2.5	4.9	4.0	...do.....	On heavy load stack smokes continuously, 40 to 50 per cent black.
11	17	.....	.....	3	85	3.8 x 3.8	14.7	4.0	Sprung..	On account of low stack draft, three boilers are used to carry load not heavy enough to keep stokers running continuously and stack smokes considerably, 10 per cent black.
12	13	.....	.....	1	110	a 4.5	15.9	3.0	.....	Coal as fired runs about 13,000 B. t. u. per pound, 11.5 per cent ash, and 2 per cent moisture. When boilers run at 75 per cent or more of their rated capacity, stack smokes badly.
13	13	.....	.....	2	90	.....	.....	.....	.....	Stack is cleaner when burning nut coal than when burning slack.
14	0	0	.....	0	200	11	95.0	3.5	.....	Coal as fired runs about as follows: Moisture, 1.40 per cent; ash, 3.40 per cent; fixed carbon, 60 per cent; volatile matter, 35 per cent. Two similar stacks; six boilers for each. Stokers carry a thick fire over entire grate.
15	90	.....	.....	0	200	9.0	63.6	5.0	.....	Coal as fired runs about 13,300 B. t. u. per pound.
16	3	.....	.....	2	95	5.0	19.6	3, 3.5	.....	Babcock & Wilcox boiler and chain grate, 2 Stirling boilers and Green chain grate. First furnace dimensions apply to Babcock & Wilcox boiler and grate. Speed of induced-draft fan controlled by steam pressure.
17	0	.....	.....	0	110	.....	.....	3.0	.....	
18	13	.....	.....	1	100	a 4.0	12.56	3.5	.....	

19	9	.....	.....	1	108	[a] 4.0	12.56	3.0	.....	
20	28	.....	.....	1	119	10	78.5	3.6	.....	
21	12	7 x 9	Near stack.....	0	200	9.0	63.6	.....	.....	Boilers have C tile on lower row of tubes within 3 feet of rear water leg. Damper regulator on main damper. Stack smokes considerably, 10 to 20 per cent black.
22	0	4½ x 5½	.....do.....	0	150	7.0	38.5	4.0	Sprung..	U tile on lower row of tubes. Secondary grates at rear of bar grate, 15 inches long by 6 feet wide; effort made to keep these well covered; area not included in grate area. Damper regulator connected to damper on each boiler. Stack is cleaner when burning No. 3 washed coal than when burning poorer grades.
23	6	.....	.....	1	150	3.25 x 6	19.5	Mohr, 4.0 Heine, 3.5	.....	C tile on secondary lower row of tubes of Heine boilers; Mohr boilers baffled vertically. Stack smokes considerably, 10 to 20 per cent black.
24	11	.....	.....	2	115	[a] 4.0	12.56	3.5	Flat.....	C tile on lower row of tubes.
25	15	7 x 9	Near stack.....	0	200	9.0	63.6	4.0	.....	Coal as fired runs 12 to 20 per cent ash. Boilers have 8 feet of C tile and 5 feet of U tile on lower row of tubes. Damper regulator on main damper is so connected that the dampers are never wide open.
26	4	.....	.....	1	225	9.0	63.6	.....	.....	This stack occasionally emitted smoke, 40 per cent black, for several minutes.
27	22	5½ x 11	Near stack.....	0	185	9.5	70.6	.....	.....	Coal as received runs about 12,000 B. t. u. per pound. All boilers are baffled alike. Boilers are run with dampers wide open; consequently boiler nearest stack runs above rating and boiler farthest from stack runs at rating or less.
28	8	4x8	.....do.....	0	150	6.0	28.3	.....	.....	Dry coal ranges from 12,500 to 13,000 B. t. u. per pound, with 5 to 14 per cent of ash. A very little smoke, 20 to 40 per cent black. Regulator on main damper. Coal is wet before firing to prevent waste into ash pit.
29	8	.....	.....	0	140	10.0	78.5	.....	.....	
30	0	0	.....	0	110	4.0	12.56	3.5	.....	Two similar stacks, each resting on rear of boilers. While this plant runs for long periods with a very good stack, it has been seen smoking many times; with furnace draft reduced to 0.04 inch water stack smokes continuously, 20 to 40 per cent black.
31	0	0	.....	0	125	[a] 5.0	19.6	3.5	.....	Coal is wet before firing to prevent waste into pit. Stack rests on rear of boilers.
32	3	.....	.....	0	130	2.5x2.5	6.3	.....	.....	Two similar stacks. Smoke noted in table due to nearly complete closure of damper.
33	30	[a] 5½	Near stack.....	1	125	[a] 5.5	23.7	3.5	.....	Coal wet before firing to prevent waste into pit.
34	31	[a] 4	.....do.....	1	110	3.8x3.8	14.4	.....	.....	
35	0	0	.....	0	135	4.0	12.56	3.6	Flat.....	Separate stack resting on rear of each boiler. Plant has variable load; sometimes dampers are nearly closed and stacks smoke badly, but usually little smoke for long intervals. Smoke observation taken when plant was running at about 118 per cent of rated capacity.
36	8	.....	.....	1	40	[a] 4.0	12.56	4.0	Sprung..	Speed of induced draft fan controlled by steam pressure.
37	22	4x6	Near stack.....	0	136	[a] 6.0	28.3	3.5	Flat.....	Stack sometimes smokes badly. Observations were taken during light load and it is probable that dampers were not open enough to furnish sufficient air.
38	0	0	.....	0	110	[a] 3.5	9.6	3.0	Sprung..	Stack rests on rear of boiler. Steam pressure controlled by hand regulation of damper. Stack is clean except when furnace draft is reduced nearly to zero, when it smokes from 20 to 50 per cent black.
39	0	0	.....	0	125	[a] 4.5	15.9	3.5	Flat.....	Two similar stacks, each resting on rear of boiler.
40	4	.....	.....	1	125	[a] 4.0	12.56	3.5	Sprung..	Plant usually runs with dampers partly closed and stack then smokes about 10 per cent black.

[a] Diameter.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Breeching.				Stack.			Ignition arch.		Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	Length (feet).	Style.	
41	7	.....	.....	0	208	11	95.0	3.0	.....	Coal as fired contains 11.50 per cent ash, 3.60 per cent moisture, and 33 per cent volatile matter, with 12,730 B. t. u. U tile on lower row of tubes of Heine boiler. Stack usually smokes 20 per cent black about half the time.
42	12	.....	.....	0	171	7.0	38.5	3.5	.....	Usually run with dampers partly closed.
43	20	.....	.....	2	220	14	153.9	3.6	.....	All flues underground.
44	0	0	.....	0	90	3.0	7.06	3.0	Sprung..	Four similar stacks, each resting on top of boiler. Steam pressure controlled by automatic regulator, which varies speed of stoker engine and position of damper.
45	0	0	.....	0	125	4.5	15.9	4.0	Flat....	Three similar stacks resting on rear of boilers. Coal is wet before firing.
46	12	.....	.....	2	125	[a] 4.5	15.9	5.0	...do....	Stack rests on rear of boiler; smokes continuously, from 30 to 60 per cent black.
47	12	.....	.....	1	125	[a] 4.5	15.9	2.8	.....	Stack rests on rear of boiler; usually smokes from 10 to 20 per cent black. Coal is wet before firing.
48	0	.....	.....	0	90	3.2	7.85	1.3	.....	Coal as fired runs about 12,400 B. t. u. per pound; 11 per cent ash; 5½ per cent moisture. Can not keep stacks clean with more than a 4-inch fire. Four similar stacks, each set on top of boiler.
49	15	8 x 10	Near stack.....	0	203	9.0	63.6	.....	.....	
50	80	7½ x 5½	.....do.....	2	325	7.7	47	.....	.....	Draft readings not of much value; dampers on boilers out of service, not being closed.
51	24	5 x 3½	.....do.....	2	125	[a] 5.0	19.6	4.0	Flat.....	U tile on lower row of tubes for 10 feet from front of furnace. Plant has automatic regulator on main damper.
52	34	4 x 4	.....do.....	2	125	[a] 6.0	28.3	4.0	...do....	C tile on lower row of tubes for 9 feet from front of furnace.
53	18	[a] 4	.....do.....	1	125	[a] 4.5	23.7	4.0	Sprung..	Large combustion chambers. Bridge wall is built up to shell and has two openings, with total area of 6 square feet. Plant usually runs with dampers partly closed.
54	30	.....	.....	1	35	[a] 4.0	12.56	4.0	...do....	Fired occasionally through inspection door. Speed of induced dra fan controlled by the steam pressure.
55	0	.....	.....	0	110	[a] 5.0	19.6	4.0	...do....	Large combustion chambers.
56	50	.....	.....	2	250	11	95.0	3.3, 5.0	.....	Coal as fired runs about 13,700 B. t. u. per pound. A considerable task to keep grates clean.
57	7	3¼ x 7	Near stack.....	0	100	4.5 x 4.5	20.25	5.75	.....	Boilers arched over top for gas passage.

[a] Diameter.

SUMMARY.

The chain-grate stoker was found in plants carrying uniform loads and in plants where loads were extremely variable. With a uniform load and a proper setting there should never be any smoke with this equipment, but when a variable load is carried a faulty method of operation may cause the emission of dense smoke. In a chain-grate plant having a variable load, with the fire carried up to the water back, a sudden release of load will require a reduction of draft. Too often the damper is nearly closed, so that the coal on the grate and the fresh coal fed to hold the fire are burned with a imited air supply, causing the stack to smoke badly.

Plants equipped with the chain grate can be made to carry a very variable load with good results by changing the thickness of the fire, the speed of the grate, and the position of the damper to suit the load. The draft should not be reduced below a certain value, which can be determined for each plant by gradually closing the damper and watching the stack. In a plant where the maximum variations of load are nearly the same, it might be necessary to vary only the speed of the grate and the position of the damper. The damper regulator is often the cause of a smoky stack, because it is usually set to choke off the entire draft, a condition which is never necessary.

Both the speed of a chain grate and the slope of the ignition arch are important. Too often the grate is run so fast that volatile matter is being driven from the coal as far back as the center of the grate; usually in this case there is not only a loss from incomplete combustion of the gases but also losses from unconsumed carbon in the ash and from injury to the grate. Live coals in the ash pit will not only warp a grate but gradually burn it up. The grate should not be run so fast that it will be hot when reentering the furnace. In one plant where a high draft was carried a sloping arch was removed and an arch built parallel to the grate. With the sloping arch the stack smoked, but with the flat arch it was entirely clean.

With chain-grate equipment a plant may run very inefficiently if the fire is carried only on the front half of the grate, as sometimes happens. When coal is burned in this way with a proper setting, it is because the fireman finds it the easiest way to carry a variable load and have a clean stack, demanding less of his attention in operation.

At some plants the boiler is forced by firing considerable coal through the inspection door. Although the desired result is accomplished by this practice, the plant becomes the equivalent of a hand-fired plant and the stack will invariably smoke badly.

FRONT-FEED STOKERS.

GENERAL DISCUSSION.

Inclined-grate stokers were patented years ago. As a result of the competition between different makers and the consequent improvement in details of construction, the present types have been evolved. They have been installed at many places and handle a great variety of coals. All those in extensive use have grates with mechanically

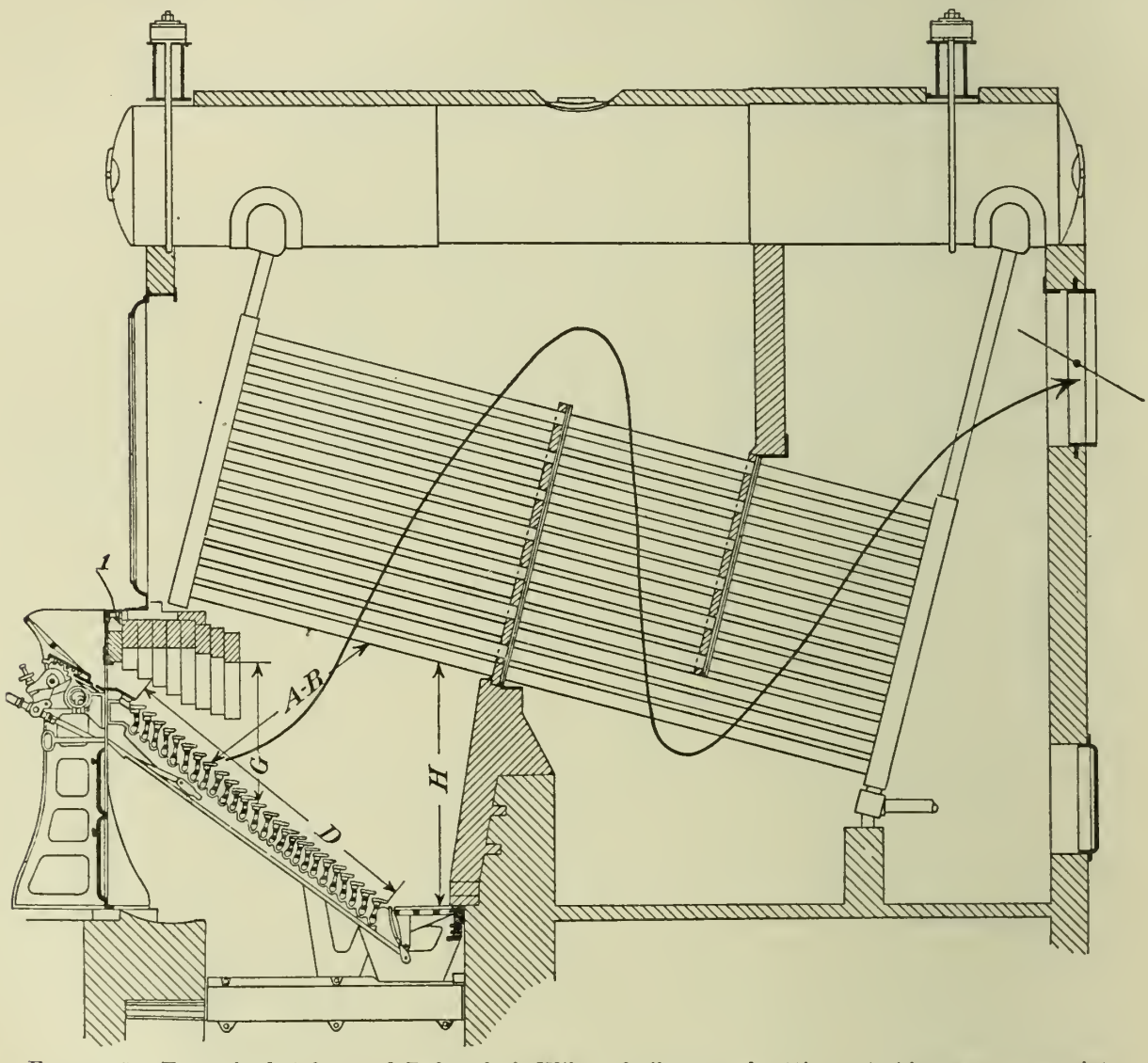


FIGURE 5.—Front-feed stoker and Babcock & Wilcox boiler, usual setting. 1, Air space; steam jets enter furnace at this point.

operated grate bars. From the difference in position of the hopper supplying the grates, these stokers are conveniently divided into two classes—front feed and side feed.

In the front-feed type the hopper is in front of the boiler, extending from side to side. Immediately back of it is sprung a coking arch, usually short. A reciprocating pusher feeds the coal to a dead plate beneath the front of the arch, where it begins to ignite. The construction and movement of the grate bars, which cause the burning coal to move down the grate, vary in different makes of this type.

These stokers can force a fire quickly and are often given severe treatment, but tests have shown that with the average setting, in

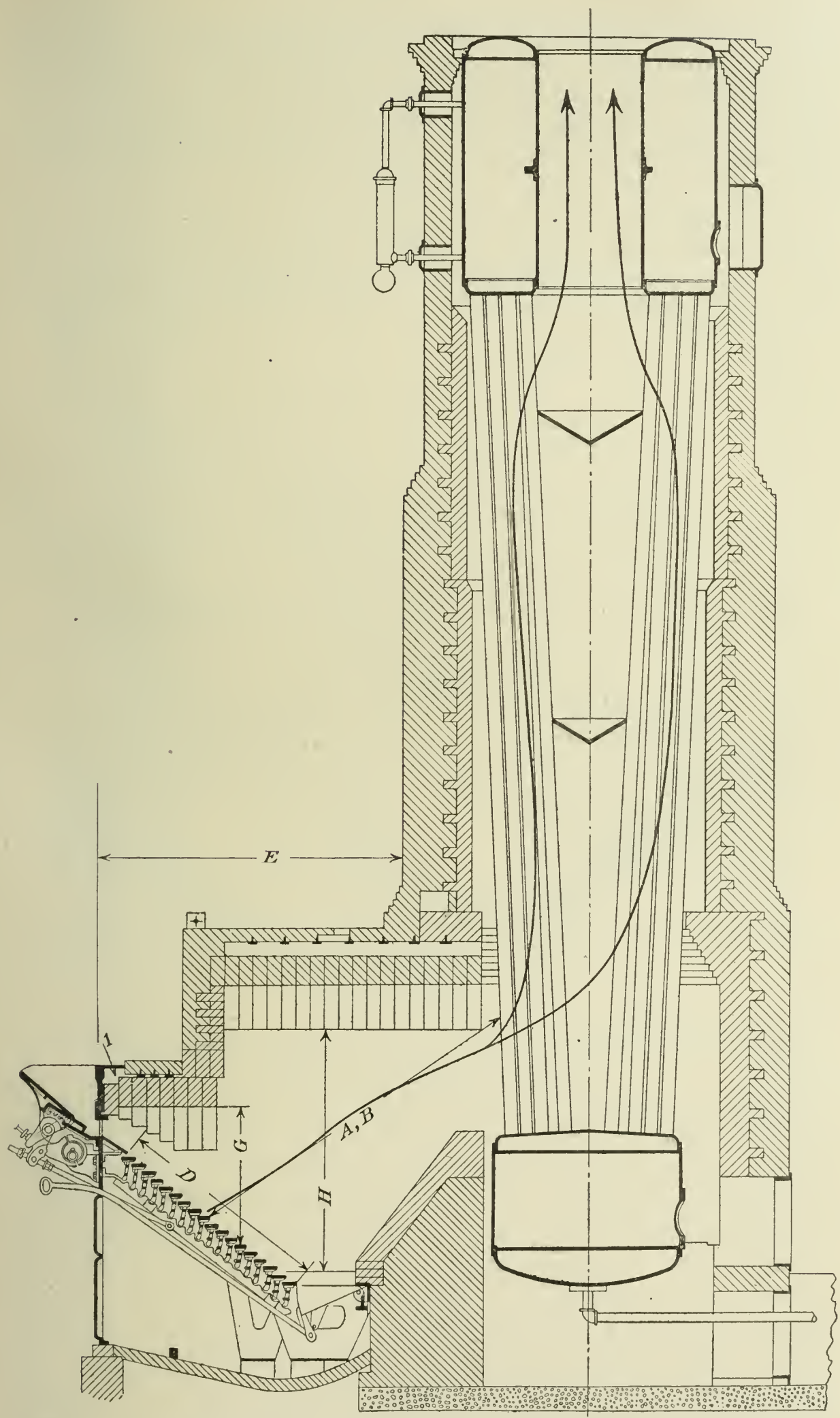


FIGURE 6.—Front-feed stoker and Cahall boiler. 1, Air space; steam jets enter furnace at this point.

which the grates are placed close to the heating surface, more than average attention is required to keep down smoke; consequently such stokers should be so set that when the fireman pushes green coal down the grate there is sufficient space for the combustion of the gases before they strike the tube heating surface. Failure to provide such space usually results in a smoky stack.

To intensify the combustion most stokers of this type are frequently set with an air space at the front of the ignition arch, through which steam jets enter the furnace. The accompanying illustrations show some boilers having stokers set in this manner. Figure 5

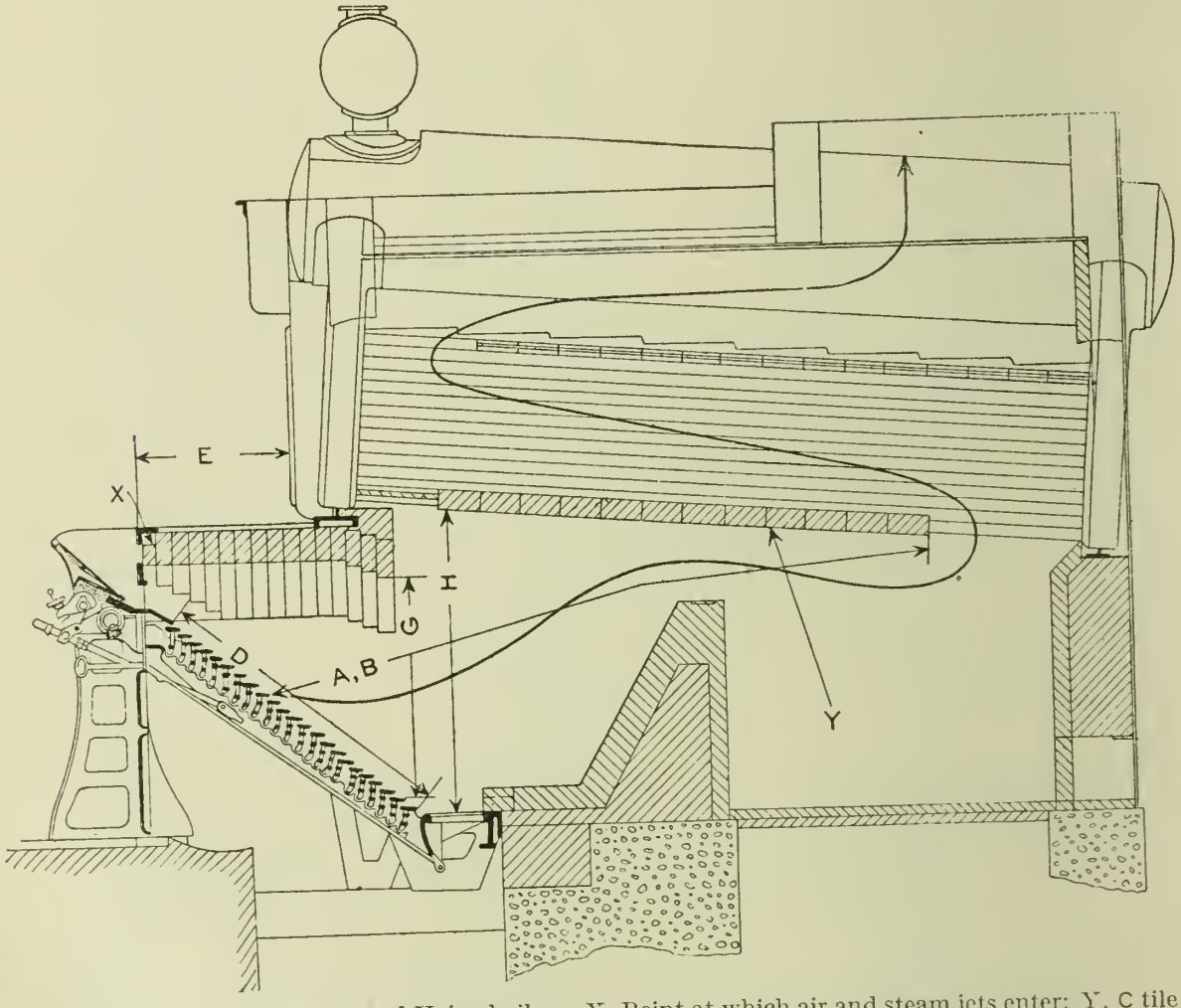


FIGURE 7.—Front-feed stoker and Heine boiler. X, Point at which air and steam jets enter; Y, C tile on lower row of tubes, forming a tile-roof furnace.

represents a Babcock & Wilcox boiler with stack at the rear and baffled so that the gases from the burning coal travel but a short distance before they strike the bottom water tubes.

Figure 6 shows a stoker of the same make as installed at a plant having Cahall water-tube boilers. Here the fire-brick arch back of the hopper covers a larger proportion of the length of the grate than in the setting illustrated by figure 5, and as the boilers are vertical the furnace is in a Dutch oven the arch of which covers the space between the ignition arch and the front tubes of the boiler. The travel of the gases to the first heating surface is much lengthened in this setting and ample space is provided for combustion when forcing the fire.

A Heine water-tube boiler, with uptake in the rear and a furnace fired by a stoker of the front-feed type, are shown in figure 7. In this installation the bottom baffling of tile on the water tubes lengthens the course taken by the gases in reaching the first heating surface. Ample space is provided for complete combustion when the boiler is carrying heavy loads.

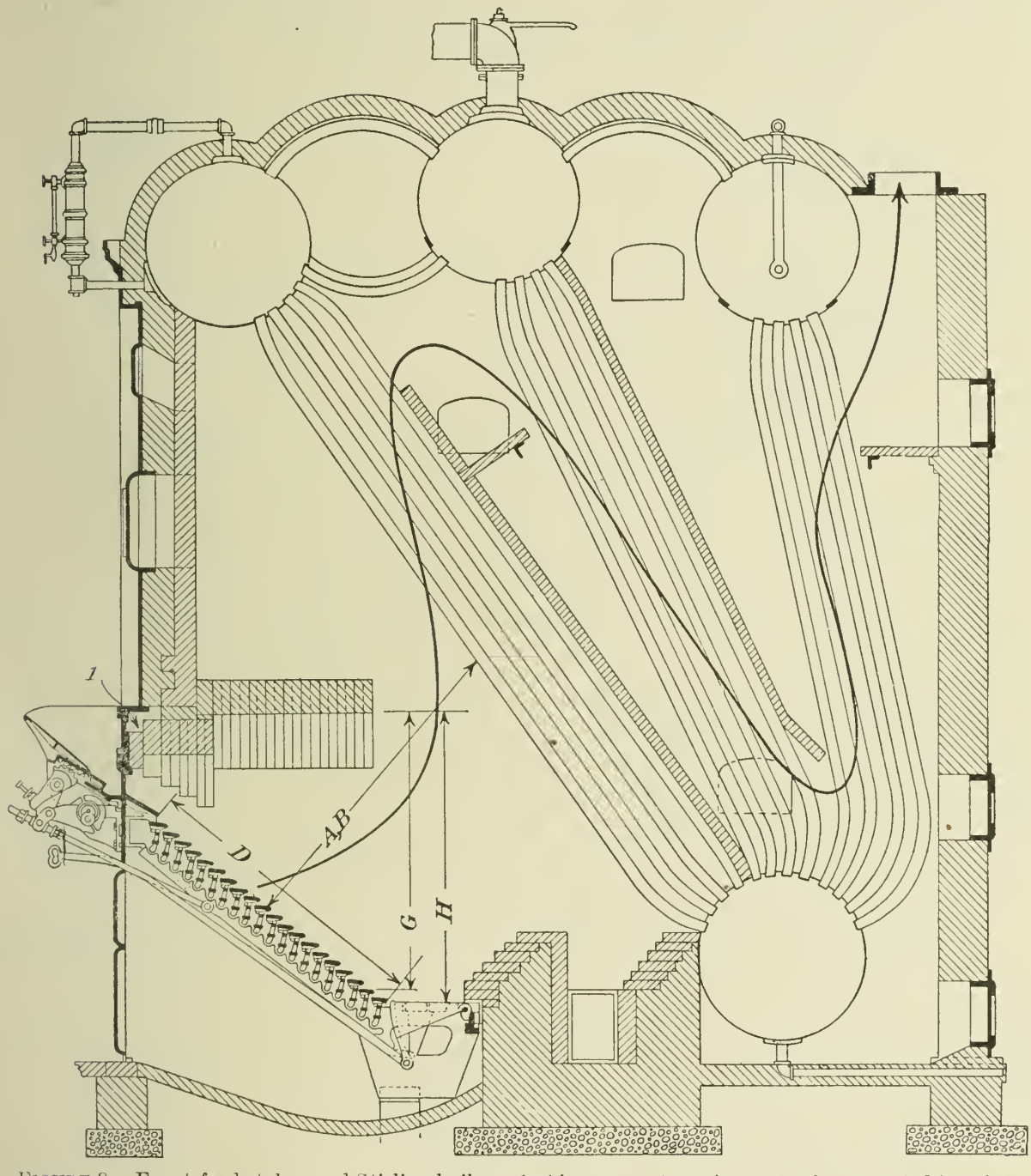


FIGURE 8.—Front-feed stoker and Stirling boiler. 1, Air space; steam jets enter furnace at this point.

Figure 8 shows the usual methods of placing a front overfeed stoker beneath the arch that is part of the regular setting of the Stirling boiler. Figure 9 represents a similar stoker, with longer ignition arch, under a return tubular boiler.

DETAILED DESCRIPTION OF PLANTS.

Detailed information was collected at 32 plants, ranging in size from 200 to 2,500 rated boiler horsepower, where front overfeed stokers were used. This information is presented in condensed form

in Table 9 (pp. 40–47), in which the same order of particulars is followed as in Table 5. In Table 9 the grate area of the front overfeed stokers includes the area of both the sloping grates and the dump grates.

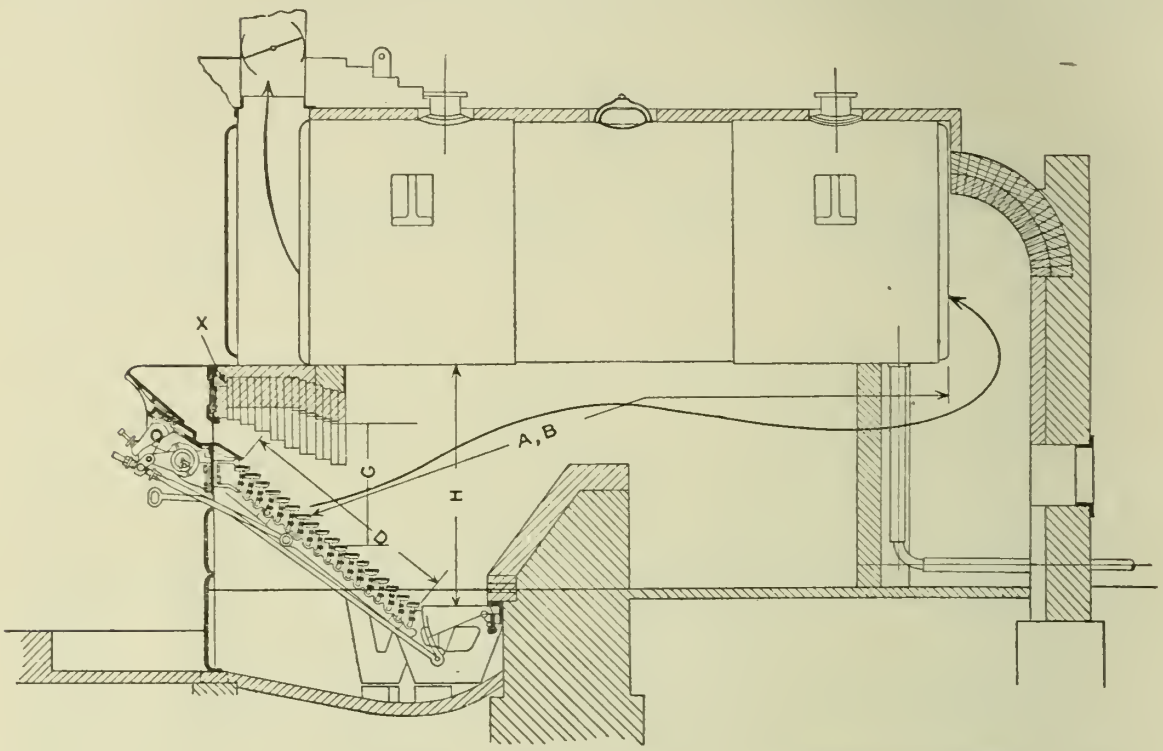


FIGURE 9.—Front-feed stoker and return tubular boiler. X, Point at which air and steam jets enter.

The different plants burned various sizes of coal, but at 11 plants the stokers were handling run of mine. The depth of fire ranged from 3.5 to 7 inches. The source of the coal and the depth of the fire are summarized in the following table:

TABLE 6.—*Kind of coal and depth of fire at plants with front overfeed stokers.*

Kind of coal.	Number of plants.	Average depth of fire.	Kind of coal.	Number of plants.	Average depth of fire.
		Inches.			*Inches.*
Illinois	10	4	Pennsylvania	4	4.5
Indiana	3	4	Virginia	1	.....
Kentucky	2	3.5	West Virginia	2	5
Maryland	8	4	Miscellaneous	1	7
Ohio	1	5			

At 40 per cent of the plants the stokers were under boiler units of 200 horsepower or less, and at 4 plants the stokers were in a Dutch oven, this setting having been installed at two plants because the boilers were of a vertical water-tube type. At 6 of the plants visited the boilers had a variable load and at 2.6 a uniform load. The least ratio of heating surface to grate surface that was determined was 28.4 to 1 and the highest 58.3 to 1, the average being 40 to 1. The coal as received burned per square foot of grate surface per hour averaged 15.6 pounds; the smallest consumption of coal per square foot of grate surface per hour was 6.4 pounds, the largest 34.7 pounds.

The percentage of the rated boiler horsepower developed on mean heavy load (the boiler being rated on 10 square feet of heating surface per horsepower) averaged 84, the lowest and highest values being 55 and 111 per cent, respectively. The percentage of boiler horsepower developed by different makes of boilers, the coal consumption, and the least and average distances from the grate to the tube heating surface have been summarized for ready reference in Table 7.

TABLE 7.—*Summary of various observations at plants with front overfeed stokers.*

Type of boiler.	Kind of coal.	Number of plants.	Furnace draft.	Coal burned per square foot of grate surface per hour, average heavy load.	Percentage of rated boiler horsepower developed, average heavy load.[a]	Distance from grates to tube heating surface.		Black smoke.
						Average.	Minimum.	
			Inch of water.	*Pounds.*		*Feet.*	*Feet.*	*Per ct.*
Babcock & Wilcox	Illinois, Maryland, Virginia and West Virginia.	9	0.31	16.8	87	6.3	5.8	7.5
Heine	Illinois, Kentucky, and West Virginia.	4	.22	12.4	81	5.0	5.0	14.1
Stirling	Illinois, Indiana, Maryland, and Pennsylvania.	5	.24	14.5	86	7.1	7.1	5.6
Miscellaneous water-tube.	Indiana, Kentucky, Maryland, and Pennsylvania.	7	.32	19.7	91	7.2	5.7	7.7
Return tubular	Illinois, Maryland, and Ohio.	7	.21	13.2	78	17.6	15.6	5.2

[a] Boiler rated on 10 square feet of heating surface per horsepower.

The average drafts, as determined at the furnace front, at the rear of the boiler, and at the base of the stack, are given in the following table:

TABLE 8.—*Summary of draft measurements at plants with front overfeed stokers.*

Type of boiler.	Measurement taken at—	Number of plants at which taken.	Average draft (inch of water).
Babcock & Wilcox	Furnace	8	0.31
	Rear of boiler	5	.36
	Base of stack	6	.87
Heine	Furnace	3	.22
	Rear of boiler	4	.48
	Base of stack	3	.76
Stirling	Furnace	5	.24
	Rear of boiler	4	.52
	Base of stack	4	.69
Return tubular	Furnace	7	.21
	Front tube sheet	4	.54
	Base of stack	3	.66
Miscellaneous types	Furnace	6	.32
	Rear of boiler	4	.43
	Base of stack	4	.76

Range of furnace draft, 29 plants, 0.09 to 0.62 inch; average, 0.26 inch. Range of draft at rear of boiler, water tube, 17 plants, 0.25 to 0.74 inch; average, 0.44 inch. Range of draft at base of stack, 20 plants, 0.38 to 1.30 inches; average, 0.76 inch. Average drop of draft from furnace to rear of boiler in water-tube boilers, 0.16 inch. Average drop from furnace to front tube sheet in return tubular boilers, 0.33 inch.

TABLE 9.—*Details of observations at plants with front overfeed stokers.*

No. of plant.	State.	Kind of stoker.	Total builders' rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
58	Illinois	Roney	1,200	Washed	Carterville, Ill	No. 5	$2.00	
59	do	do	300	do	Ladd, Ill	No. 2		
60	Pennsylvania	do	1,400	Georges Creek	Maryland	Run of mine		
61	Maryland	do	800	do	do	do		
62	do	do	800	do	do	do		
63	do	do	700	do	do	do		
64	do	do	750		Virginia	do		
65	Missouri	do	2,700	Various coals		Screenings		33,200
66	Ohio	do	600	Pocahontas	West Virginia	Nut and slack	2.25	2,600
67	Missouri	do	500	Various washed coals	Illinois	Slack	1.30	2,440
68	do	do	300	Belleville	do	do	1.40	1,445
69	Ohio	do	1,800	Laurel; Jellico	Kentucky	Nut and slack	2.00	
70	do	do	230	Pocahontas	West Virginia	Run of mine	2.70	900
71	Missouri	do	750	Belleville	Illinois	Screenings	1.15	
72	do	do	600	Stanton	do	Slack	1.00	1,300
73	do	do	500	Belleville	do	do	1.35	1,364
74	do	do	375	Washed	Carterville, Ill	No. 4	2.12	1,300
75	do	do	330	do	do	do	1.90	2,567
76	Maryland	do	500	Georges Creek	Maryland	Run of mine		
77	Ohio	do	480	Glen Run	Ohio	Slack		
78	Missouri	do	500	Washed	Collinsville, Ill	Pea	1.50	5,000
79	Indiana	do	260		Indiana	Nut and slack		
80	Maryland	do	700	Georges Creek	Maryland	Run of mine		
81	do	do	500	do	do	do		
82	Ohio	do	1,740	Pittsburg	Pennsylvania	Slack	1.30	30,000
83	Indiana	do	450		Indiana	Nut and slack		
84	do	do	300		do	do		
85	Kentucky	do	900		Kentucky	do		
86	Maryland	do	200	Georges Creek	Maryland	Run of mine		
87	Pennsylvania	do	2,800	River coal	Pittsburg, Pa	1¼-inch slack		
88	New York	Wilkinson	1,100	Rochester; Pittsburg	Pennsylvania	Various sizes	1.95–2.10	10,800
89	Maryland	Roney	800		do	Run of mine	2.79	

TABLE 9.—*Details of observations at plants with front overfeed stokers*—Continued.

No. of plant.	Load.			Rating.							
	Requirement.	Nature.	Character.	Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builders' rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
				Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
58	Power and heat	Uniform	Office building	24	60	24	20	26	26	111	111	5
59	Power, light, and heat	do	do	10	7.5	10	5.5	18.3	15.8	90	100	5
60	Power and heat	do	Factory	24	50	24	50	17.4	17.4	75	75	4
61	Power, light, and heat	do	Rolling mill	7.5	4.6	.....	.....	11	11	67	76	4
62	do	do	do	3.5	4.5	.....	.....	15.2	15.2	96	108	4
63	do	do	do	8	9	8	9	14.8	14.8	83	80	4
64	Power and heat	do	Office building	12	12	12	6	16.6	16.6	94	100	4
65	Power, light, and heat	Variable	Depot	24	125	24	50	14.5	13.1	78	78	5
66	do	Uniform	Office building	12	7.5	12	7.5	17.4	17.4	89	93	4.5
67	do	do	Mill	10	8.5	10	7.5	11.7	11	67	68	5
68	do	do	Factory	10	5.75	10	4	11.8	10	77	77	5
69	do	Variable	Brewery	24	71	24	39	13.3	11.2	77	66	5
70	do	Uniform	Office building	14	2.5	12	1.3	12.6	10.3	103	78	4
71	do	do	Factory	10	8	10	8	23.5	23.5	98	85	5
72	Power and light	do	Brick manufacture	12	4.3	12	4.3	6.4	6.4	55	48	5
73	Power, light, and heat	do	Factory	10	4	10	3.5	16.4	15.3	93	64	5
74	do	do	do	24	8.25	12	4.25	9.2	9.2	57	55	5
75	do	do	Bakery	10	5	10	5	13.3	13.3	93	91	5
76	do	do	Ice plant	11	6.5	11	6.5	13.3	13.3	91	120	4
77	Power and heat	do	Oil refinery	24	20	24	20	10.1	10.1	57	69	5
78	Power, light, and heat	Variable	Manufacturing	12	5.5	12	9	12.1	11	75	75	5
79	do	Uniform	Factory	10	6.5	10	6.5	17.3	17.3	100	100	5
80	do	do	Rolling mill	8	9	8	9	14.8	14.8	79	80	4
81	do	do	do	6.25	4.5	6.25	4.5	12.3	12.3	.....	72	4
82	do	do	Salt works	24	82	24	82	15.8	15.8	88	88	4.5
83	do	do	Factory	10	11	10	11	20	20	98	98	5
84	do	do	Hospital	24	12	24	10	14.4	13.2	67	67	5
85	do	Variable	Office building	24	28	24	20	34.7	29.0	.....	111	5
86	do	Uniform	Rolling mill	8	3.4	8	3.4	17.3	17.3	94	106	4
87	Power	Variable	do	24	100	.....	.....	.....	14.4	104	100	4
88	Power, light, and heat	do	.....	12	17	12	10.5	13	10.9	.....	58	4.5
89	Power	Uniform	Pumping station	24	26	24	26	19	19	.....	120	4.5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 9.—*Details of observations at plants with front overfeed stokers*—Continued.

No. of plant.	Stoking.		Boilers.									
	Thickness of fire (inches).	Frequency of cleaning fire.	Type.	Size.	Number installed.	Number used to carry—		Builders' rated horsepower.	Horsepower, boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
						Average heavy load.	Average light load.					
58	3 -4	8 times in 24 hours	Babcock & Wilcox water-tube.	140 4″ x 18′ tubes, 2 36″ drums	4	3	1	300	300	3,000	0	165
59	2.5-3	2 to 3 times in 10 hours.	Standard; Babcock & Wilcox.	80 4″ x 18′ tubes	2	2	2	150	167	1,670	0	125
60	3 -4		Babcock & Wilcox water-tube.	168 4″ x 18′ tubes, 2 42″ x 20 3/10′ drums.	4	4	4	350	350	3,500	0	150
61			do	108 4″ x 18′ tubes, 2 36″ x 18′ drums.	4	2		200	226	2,260	0	140
62			do	108 4″ x 18′ tubes, 2 36″ x 18′ drums.	4	3		200	226	2,260	0	100, 140
63			do	162 4″ x 18′ tubes	2	2	2	350	340	3,400	(a)	140
64		2 times in 24 hours	do	126 4″ x 18′ tubes, 2 30″ drums	3	2	1	250	264	2,640	0	60
65	7		do	126 4″ x 18′ tubes	10	10	5	270	266	2,660	0	160
66	6	4 times in 24 hours	do	168 4″ x 16′ tubes, 2 30″ x 16′ drums.	2	1	1	300	313	3,130	0	140
67	3	3 times in 12 hours	Heine water-tube	138 3½″ x 18′ tubes	2	2	2	250	253	2,530	0	140
68	5	5 times in 10 hours	O'Brien and Heine water-tube.	85 3½″ x 18′ tubes, 78 3½ x 18′ drums.	2	2	2	175, 125	156, 143	1,560, 1,430	0	140
69	3.5	Variable	Heine water-tube	140 3½″ x 18′ tubes	6	6	5	300	256	2,560	0	110
70	3 -4	Once in 14 hours	do	53 3½″ x 16′ tubes	2	1	1	115	87	865	0	85
71	2	2 times in 10 hours	Bronson special fire-tube.	84″ x 18′, 150 3½″, 18 4″ x 18′ water tubes.	2	1	1	375	325	3,250	0	140
72	2.5	2 times in 12 hours	Return tubular	60″ x 16′, 44 4″ tubes	6	3	3	100	87	870	0	110
73	4	3 times in 10 hours	do	72″ x 20′, 70 4″ tubes	2	1	1	250	172	1,725	0	145
74	5	3 times in 12 hours	do	66″ x 18′, 54 4″ tubes	3	2	2	125	120	1,200	0	130
75	5	2 times in 10 hours	do	66″ x 16′, 54 4″ tubes	3	2	2	110	107	1,065	0	110
76			do	72″ x 18′, 74 4″ tubes	4	2	2	125	164	1,640	0	85
77	4 -5	4 times in 24 hours	do	4 60″ x 16′, 46 4″, 2 60″ x 16′, 54 4″.	6	6	6	80	107, 93	1,065, 932	0	75-80
78	4	2 times in 12 hours	Stirling water-tube	192 3¼″ tubes	2	1	2	250	250	2,500	0	125
79	3 -4	2 times in 10 hours	do	198 3¼″ tubes, 3 36″ drums	1	1	1	260	260	2,600	0	120
80			do	259 3¼″ tubes, 2 42″ x 12 3/10′ drums.	2	2	2	350	354	3,540	(b)	140
81			do		1	1	1	500			0	140
82			do		5	5	5	230, 525	230, 521	2,300, 5,208	0	125

83	3	-4	2 times in 10 hours	Wickes vertical water-tube.	112 4″ tubes	2	2	2	225	225	2,250	0	120
84	3	-4	4 times in 24 hours	Atlas water-tube	63 4″ x 18′ tubes	3	2	2	150	150	1,500	0	100
85		3		Henry Vogt water-tube.		3	2	1	300			0	125
86				Cahall vertical water-tube.	108 4″ x 18′ tubes	1	1	1	200	226	2,260	0	100
87	4	-6	2 to 3 times in 24 hours.	Rust water-tube		8	6	5	350	335	3,350	0	150
88		4	4 times in 24 hours	Standard water-tube		4	4	4	250, 350	—, 268	——, 2,680	0	175
89			do	National water-tube		4	2	2	200			0	140

[a] 125° F. at boiler.

[b] 175° F. at boiler.

TABLE 9.—*Details of observations at plants with front overfeed stokers*—Continued.

No. of plant.	Furnaces. Number.	Kind.	Grate area per boiler (square feet).	Dimensions (feet). Distance from grates to tube heating surface. Average (A).	Minimum (B).	Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance from grates to coking arch. At front (F).	At rear (G).	Height of arch at rear of furnace (H).
58	4	Plain	64		5			2			
59	2	Dutch oven	42.5, 39.5	9.5	7	5.5 5	6	9			4
60	4	Plain	60			8	7.5	0			
61	4	.....do	56.3	5.5	5.5	7.5	7.5	0		3.2	
62	4	.....do	57	5.5	5.5	7.5	7.5	0		3.2	
63	2	.....do	76	5.5	5.5	9	8.5	0			
64	3	.....do	60	6	6	8	7.5	0			
65	10	.....do	72			8	9				
66	2	.....do	72	5.5	5.5	8	9	0			
67	2	Tile roof	72.25			8.5	8.5	0			
68	2	Plain	55.25, 42.25			6.5	[a]8.5, 6.5				
69	6	.....do	73	6	6	4.3	8.5	0			
70	2	.....do	28.6	4	4	4.4	6.5	0			
71	2	Tile roof	68	8	5.5	8	8.5	0			
72	6	Plain	37.5	15	13	5	7.5	0			
73	2	.....do	48	18.5	15.5	5.5	8.5	0			
74	3	.....do	37.5			5	7.5				
75	3	.....do	37.5			5	7.5				
76	4	.....do	45	18	17	6	7.3	0			6.5
77	6	.....do	27.5	19	17	5	5.6	0			
78	2	.....do	76			8	9.5				
79	1	.....do	75	7	7	8.3	9	0			6.8
80	2	.....do	76	7.25	7.25	9	8.5	0			6.75
81	2	.....do	117	7.25	7.25	6.5	9	0			
82	5	.....do	76, 104.5	[b]6.5, 7.5	[b]6, 7	[b]8, 11	9.5	0			[b]7.25, 8.5
83	2	Dutch oven	55			5.5	10	6.75			
84	3	Plain	34.64			4.3	8	0			
85	3	.....do	48			6	8	0			
86	1	Dutch oven	49	10.5	8			6			
87	8	.....do	83	7	5	10	7	9.5			5
88	4	Plain	52.5, 59.5	4	4	8.5, 7.5	7	0	0.3		
89	4	.....do	57								

[a] First dimension applies to O'Brien boiler.

[b] First dimension appli es to small boiler.

TABLE 9.—*Details of observations at plants with front overfeed stokers*—Continued.

No. of plant.	Kind.	Draft. Readings (inches of water). Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.	Conditions under which readings were taken.	Smoke records. Number of observations.	Total length of observations (minutes).	Average for 1 hour (minutes). 100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.	Average percentage of black smoke.	Load during observations.
58	Chimney..	0.30-0.33	0.64	.....	1.14	.....	Damper and poke-hole doors open.	5	333	0	0	50	4.4	Average.
59	...do.....	.12- .24	.36	.....	.52	.....	Dampers open.....	1	60	0	0	56	.6	Light.
60	...do.....	.18- .25	.....	.....	.70	.....	.....do.....	2	59	0	2	50	3.9	Average.
61	...do.....	.19- .21	.25	.....	.32	0.65	.....do.....	1	93	0	7	48	7.4	
62	...do.....	.17- .22	0.25- .32	.....	.32	.70	.....do.....	1	93	2	9	25	16.5	
63	...do.....	.38- .46	.....	.....	.....	.60	.....do.....	1	93	0	2	52	3.4	
64	...do.....	.50- .57	.....	.....	1.10	1.25	.....do.....	2	195	0	0	0	5	Do.
65	...do.....	.25- .50	.....	.....	.80- .90	1.10	.....	1	60	0	0	0	19	Light.
66	...do.....	.....	.25	.....	.....	.90	Damper half open.....	(a)	(b)	0	0	.....	.....	Average.
67	...do.....	.20	.44	.....	.....	.64	.....	1	60	0	0	52	3.7	Do.
68	...do.....	.25	.50	.....	.....	.54	.....	1	60	0	0	0	10.7	Light.
69	...do.....	.18- .22	.35- .40	.....	.40- .45	1.10	Damper open.....	2	120	0	12	0	28	Do.
70	...do.....	.....	.60	c 0.40	.90	.....	.....do.....	(a)	(b)	0	0	.....	.....	Heavy.
71	...do.....	.30	.....	.60	.....	.70	.....	1	60	0	0	54	2.7	Average.
72	...do.....	.16	.....	.38	.....	.....	.....	1	60	0	0	0	19.2	Do .
73	...do.....	.30	.....	.44	.....	.....	.....	1	60	0	0	55	4.2	Do.
74	Chimney; induced.	.09	.....	.....	.....	.47	Fan not running.....	1	60	0	0	54	10	Do.
75	Chimney..	.20	.....	.....	.....	.80	Damper open.....	1	60	0	0	60	0	Do.
76	...do.....	.21- .25	.....	.....	.55	.....	.....do.....	1	120	0	0	60	0	Do.
77	Induced...	.05- .07	.....	.15- .17	.48- .95	.....	.....	1	60	0	0	60	0	Do.
78	Chimney..	.16	.64	.....	.....	.64	.....	1	60	0	3	28	16.6	Light.
79	...do.....	.25	Lower rear, .47	.....	.64	.....	Dampers open.....	1	62	0	0	55	.1	Average.
80	...do.....	.21- .33	Lower rear, .41- .48	.....	.....	.55	.....do.....	1	93	0	4	55	2.8	
81	...do.....	.28	{Lower, .45 {Upper, .60	.....	.....	.65	Damper open.....	1	93	0	2	52	3.1	
82	...do.....	.10- .40	Upper rear, .50- .60	.....	.....	.80-1.0	.....	1	600	0	2.5	51	5.5	Do.
83	...do.....	.20	Lower rear, .26	.....	.71	.....	Dampers open.....	1	62	0	6	40	10	Do.
84	...do.....	.20- .25	.39- .41	.....	.....	.55	.....do.....	2	80	0	0	(d)	17.1	Light.
85	...do.....	.26	.74	.....	1.15	.....	.....do.....	2	170	3	8	34	18	Do.
86	...do.....	.28	Lower rear, .30	.....	.....	.38	.....do.....	1	93	1	2	59	2.5	Average.
87	...do.....	.26- .40	.....	.....	.....	.75- .85	.....	1	60	0	0	59	.3	Heavy.
88	...do.....	.....	.....	.....	.....	.....	.....	1	60	0	0	43	6.3	Light.
89	...do.....	.58- .66	.....	.....	1.10	1.30	Dampers open.....	1	60	0	0	60	0	Average.

a Several. b Various lengths. c Front water leg. d Variable.

TABLE 9.—*Details of observations at plants with front overfeed stokers*—Continued.

No. of plant.	Breeching. Length from stack to nearest boiler (feet).	Breeching. Size (feet).	Breeching. Place at which measurement was taken.	Breeching. Number of elbows between boiler and stack.	Stack. Height (feet).	Stack. Size (feet).	Stack. Area (square feet).	Length of coking areh (feet).	Remarks.
58	25	5 x 5	Near boiler.....	0	265	*a* 6	28.3	2.4	Bar never inserted through poke holes in front of furnaces. Four $\frac{1}{8}$-inch steam jets on each boiler run continuously. Stack sometimes smoked badly for several minutes. Always run with poke-hole doors open.
59	10	.....	.....	2	121	2 x 7.5	15	.....	Fire never poked through poke holes. Two $\frac{1}{8}$-inch steam jets on each boiler used continuously. Run with poke-hole doors open.
60	5	.....	.....	0	150	*a* 6	28.3	.....	Steam jets across front of furnace used continuously.
61	0	.....	.....	0	150	*a* 6	28.3	3	
62	0	.....	.....	0	150	*a* 6	28.3	3	Coal runs about 12 per cent ash.
63	5	.....	.....	0	125	*a* 6	28.3	3	
64	6	.....	.....	0	220	*a* 5	19.6	2.8	Fire poked through poke holes very carefully. Stack smokes nearly continuously, 5 per cent black. Automatic regulator on main damper.
65	30	7 x 17.5	Near stack.....	0	200	*a* 12	113.1	2.2	Steam jets run continuously. Stack smokes steadily from 10 to 40 per cent black.
66	8.5	.....	.....	1	260	*a* 4	12.56	3	Steam jets used part of time.
67	12	3.5 x 4	Near stack.....	0	90	*a* 4.3	14.7	3	Steam jets run continuously.
68	40	5 x 3.5	.....do.....	1	140	*a* 5	19.6	.....	C tile on lower row of tubes. Steam jets run continuously. Smoked steadily, 10 to 20 per cent black. Some refuse burned.
69	3	.....	.....	1	164	*a* 5	19.6	3	V tile on lower row of tubes. Stack smoked continuously, 10 to 40 per cent black.
70	55	*a* 5	Near stack.....	4	175	*a* 3.5	9.7	.....	V tile on lower row of tubes.
71	12	.....	.....	1	125	*a* 7	38.5	4	Steam jets used continuously.
72	0	0	.....	0	78	*a* 3	7.06	2	Steam jets run continuously. Three similar stacks, two boilers per stack, resting on front of boilers. Stacks smoke continuously, 10 to 40 per cent black.
73	17	.....	.....	2	128	*a* 5	19.6	.....	Steam jets run continuously.
74	45	.....	.....	3	125	3 x 2	6	.....	Induced draft used on heavy load. Regular steam jets installed, besides two more steam jets entering through front of furnace, all run continuously. Some refuse burned.
75	20	4.5 x 3.5	Near stack.....	1	120	4.5 x 4.5	20.25	2.5	Steam jets run continuously.
76	2	.....	.....	0	.....	.....	.....	2.7	Steam jets used.
77	19	.....	.....	3	30	*a* 5	19.6	.....	Four $\frac{3}{32}$-inch steam jets to each boiler used continuously. Some smoke in cleaning fire, usually about 20 per cent black.
78	0	0	.....	0	100	*a* 4	12.56	.....	Steam jets run continuously.
79	6	.....	.....	0	105	*a* 5	19.6	.....	Four steam jets run continuously.
80	0	0	.....	0	96	*a* 4	12.56	.....	Two similar stacks resting on rear of boilers.

81	0	0	.....	0	96	*a* 4	12.56	1.75	Stack rests on rear of boilers.
82	0	82	.....	0	120 110	*a* 5 *a* 3.3	19.6 8.8	.....	Three boilers have four $\frac{1}{8}$-inch jets and two boilers six $\frac{1}{8}$-inch jets. Separate stack resting on the rear of each boiler; three 110-foot stacks and two 120-foot stacks.
83	6	.....	.....	0	105	*a* 5	19.6	.....	Three steam jets on each boiler run continuously.
84	9	.....	.....	1	130	*a* 5.5	23.7	3	Two steam jets per boiler run continuously. Automatic regulator on main damper. Stacks smoke from 20 to 50 per cent black when regulator closes damper.
85	40	.....	.....	0	195	*a* 5	19.6	2.5	Six $\frac{1}{16}$-inch steam jets on each boiler run continuously.
86	0	0	.....	0	50	*a* 4	12.56	.....	Coal runs about 12 per cent ash. Stack rests on top of boiler. This stack was seen to smoke three times in a 93-minute observation for only one-half minute each time.
87	8	.....	.....	0	120	*a* 4	12.56	2.75	Coal as fired runs about 13,500 B. t. u. per pound. Five $\frac{1}{8}$-inch steam jets across front of furnace run continuously. Eight similar stacks.
88	11	.....	.....	0	130	5 x 5	25	3	Twenty-three and twenty-six $\frac{1}{16}$-inch steam jets across front of furnace; are hand operated and do not run continuously.
89	10	.....	.....	1	150	*a* 6	28.3	.....	Three $\frac{1}{8}$-inch steam jets in furnace and fifteen $\frac{1}{8}$-inch steam jets above the first gas passage, all run continuously.

a Diameter.

SUMMARY.

A review of the remarks in the preceding table shows that with the front overfeed type of mechanical stoker, success in smoke abatement has been attained by one of three methods—the continuous use of steam jets, a generous admission of air, or careful operation.

SIDE-FEED STOKERS.

GENERAL DISCUSSION.

Like the front feed, the side-feed stoker has been in use for many years, the first American patent for this type having been taken out in 1878. Several firms now make such stokers, which differ chiefly in the manner of feeding coal and getting rid of clinkers and ash. In all the coal is fed from two magazines, one at each side of the boiler. At the bottom of each magazine is a flat built-up iron and steel plate called the coking plate; beneath this is an air duct and on it rests the coal-feeding mechanism. Over this feeding device is a heavy casting, the arch plate, on which rests a fire-brick arch extending over the whole grate area and having along the upper side an air duct connected with the fire space by small openings in the skew-backs supporting the arch. These openings are designed to admit hot air above the coal at a point where the volatile hydrocarbons are given off. The movable grate bars and a clinker-breaking device at the bottom of the V-shaped space between the grates are actuated by a small engine that forms part of the equipment.

Stokers of the side overfeed type are characterized by large coking space per foot of grate area and an ample combustion chamber. They have been installed at both large and small plants, and are successfully carrying both uniform and variable loads. In the field investigation here reported no other type of stoker was found doing as well under so great a variety of conditions. Its chief defect seems to lie in the devices for getting rid of the ash. Though supposedly automatic, they often require the service of a fireman. This introduces an element of varying value in the operation of the plant.

The two makes of this stoker that are most used formerly differed in arch construction, one having only side arches over the coking plates. As now installed, the arch in both makes extends over the grate area and the two styles differ merely in the devices for distributing coal to the grate and for getting rid of refuse. One employs for coal distribution a shaft rotating through a small arc to move stoker boxes on the coking plates; as the boxes work forward, they push coal toward the edge of the plates. Between the lower ends of the grates and supported by a bearing shaft is a hollow iron bar with projections on its surface; this bar, when rotated, grinds up the clinker. The other make feeds the coal by a screw and has heavy iron

disks actuated by a reciprocating bar for crushing clinker. Both these stokers are frequently set in Dutch ovens.

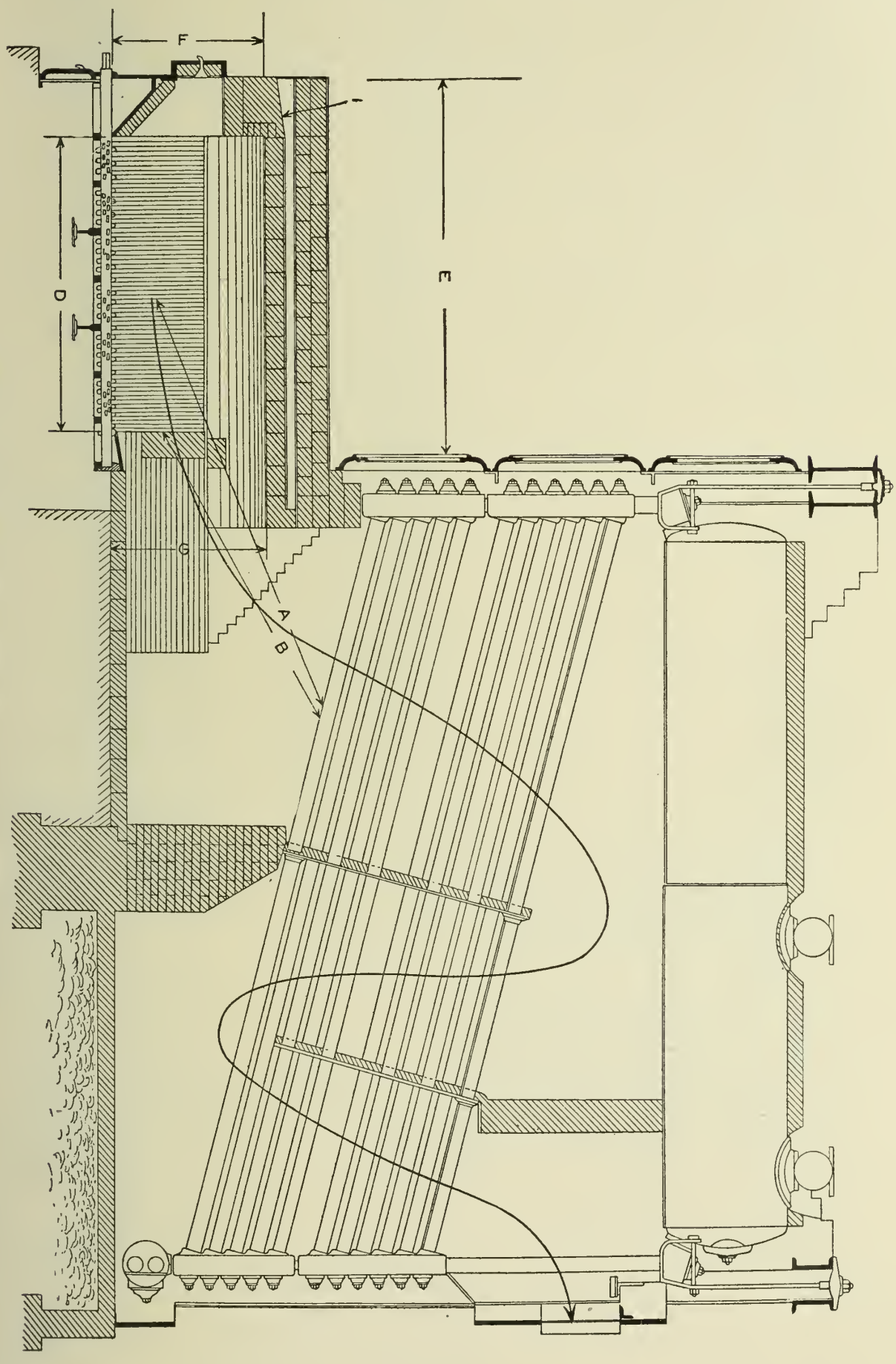


FIGURE 10.—Side-feed stoker in Dutch oven and Babcock & Wilcox boiler.

Figure 10 shows the stoker first mentioned in a Dutch oven having a chamber above the arch for heating the air admitted over the coal,

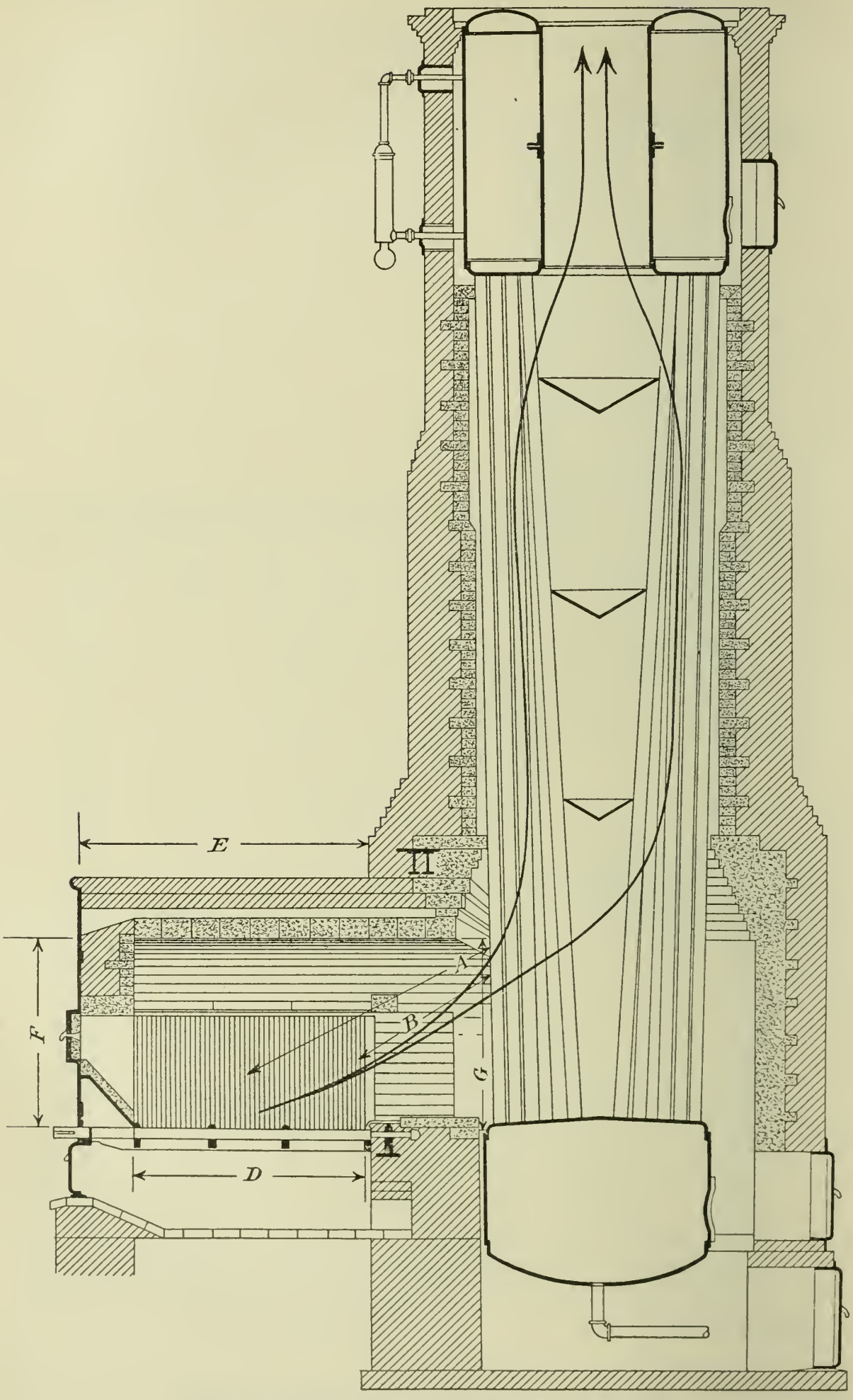


FIGURE 11.—Side-feed stoker in Dutch oven and Cahall boiler.

as set at a battery of Babcock & Wilcox boilers. This setting, with its ample combustion chamber and fairly long travel from the grates

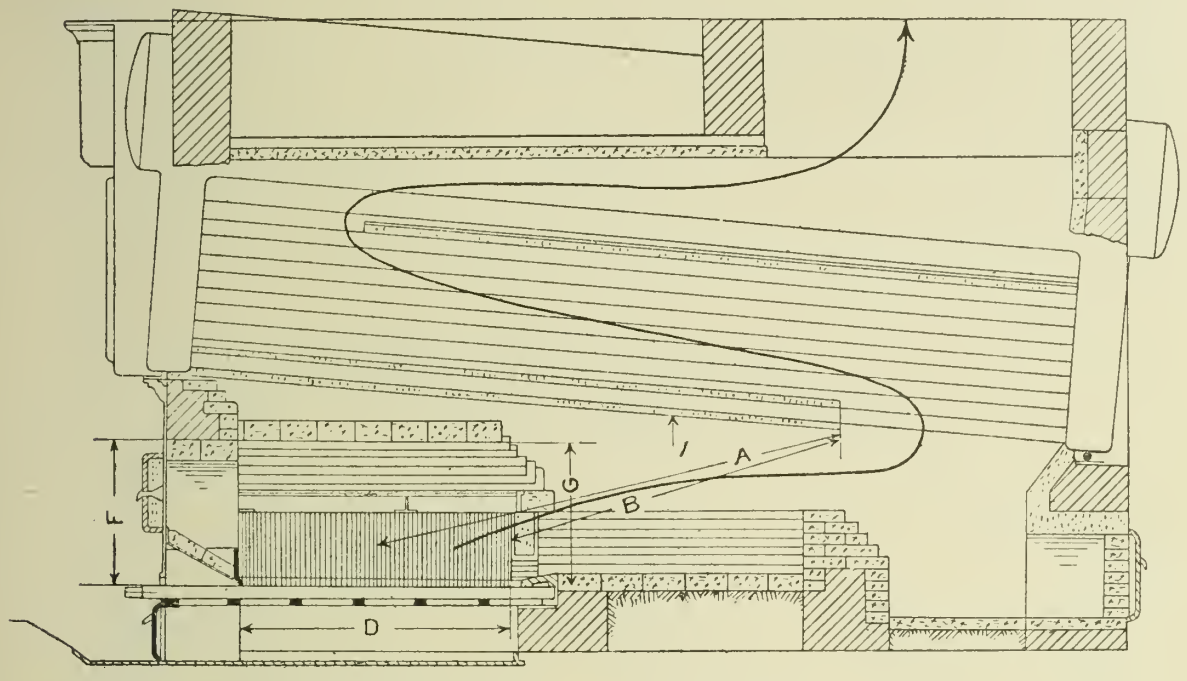


FIGURE 12.—Side-feed stoker and Heine boiler. 1, C tile on lower row of tubes, forming a tile-roof furnace

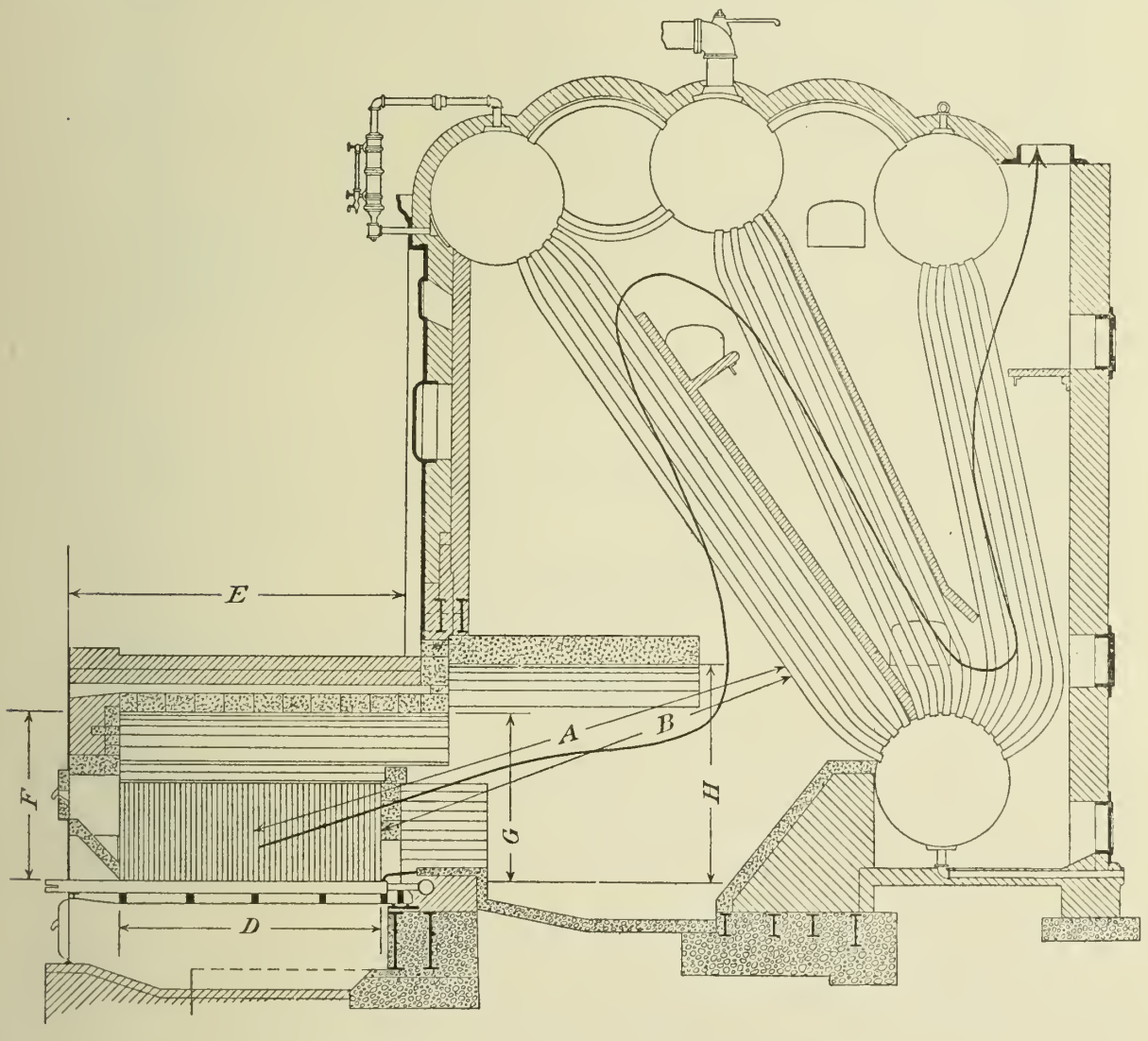


FIGURE 13.—Side-feed stoker in Dutch oven and Stirling boiler.

to the tube heating surface, allows nearly perfect combustion of the hydrocarbons from the bed of coal.

The other make of stoker as installed under a Cahall boiler is shown in figure 11. As the boiler is vertical, the stoker is placed in a Dutch oven. In this setting also, the combustion chamber is large enough to permit thorough mixing of the gases from the burning coal and a moderately long travel from the grates to the first row of water tubes.

A side-feed stoker set in a Dutch oven under a Heine boiler is shown in figure 12. The ignition arch extends over the grates, and by baffling the bottom row of tubes the space between the back of the

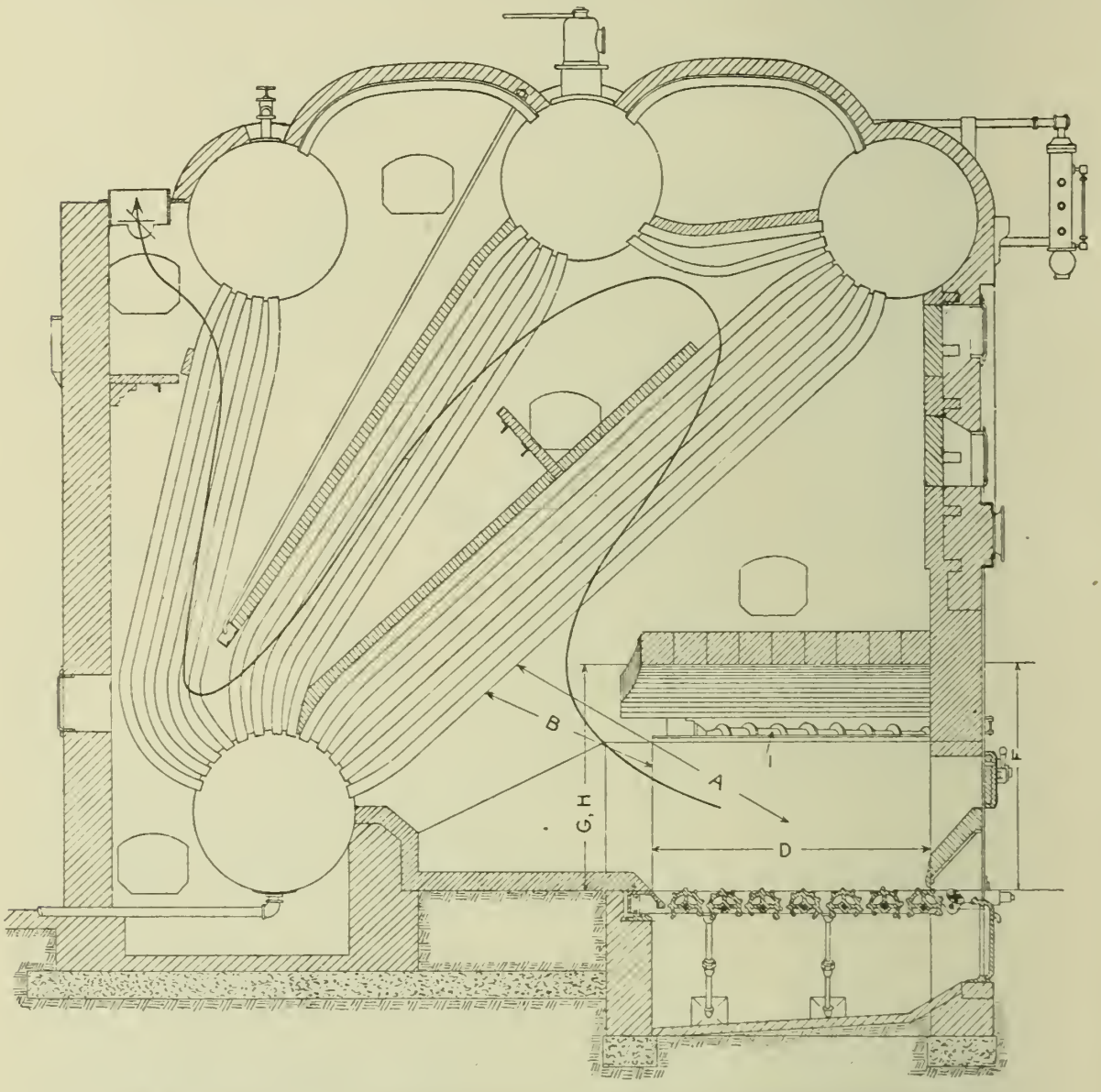


FIGURE 14.—Side-feed stoker and Stirling boiler. 1, Continuous screw for distributing coal.

arch and the rear end of the baffling becomes a tile-roofed furnace. The gases are given a long journey from fire to heating surface, and the construction insures a smokeless fire under heavy loads and forced feed.

The chief difference in the two patterns of side-feed stokers under discussion are shown in the accompanying illustration of these stokers under Stirling boilers. Figure 13 shows the stoker first mentioned set in a Dutch oven. The feeding device is not shown, but the rotating clinker bar is. In figure 14 the screw for feeding coal and the

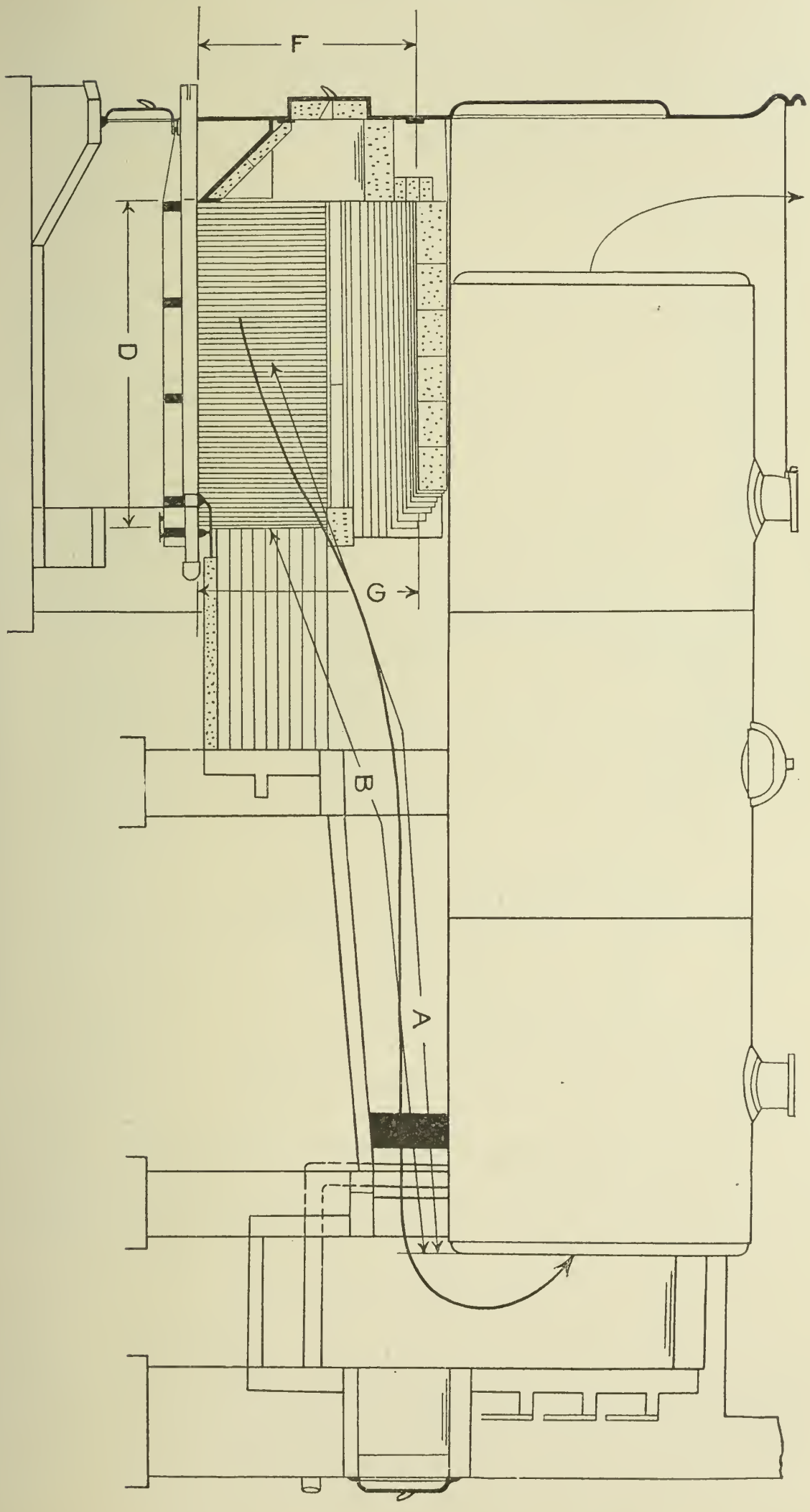


FIGURE 15.—Side-feed stoker and return tubular boiler, elevation.

device for crushing clinker, the special features of the other make of stoker, are evident. One stoker is set in a Dutch oven; the other is placed beneath the arch that is a characteristic feature of the Stirling boiler. Both installations exhibit a meritorious feature of the side-feed stoker—the large combustion space over the grates.

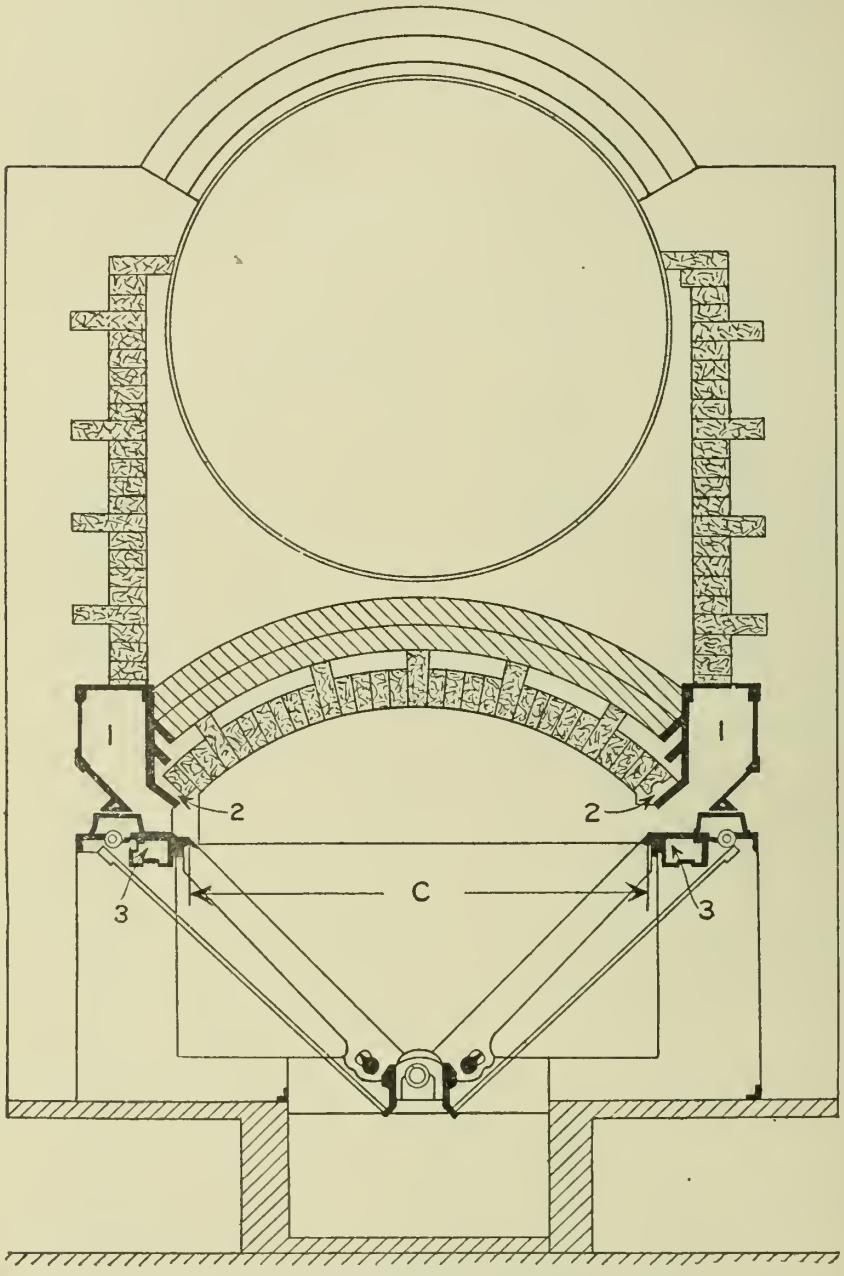


FIGURE 16.—Side-feed stoker and return tubular boiler, cross section. 1, Coal magazines; 2, hot-air ducts; 3, air-admission openings under coking plates.

The fact that a large number of the plants visited have a side-feed stoker under a return tubular boiler indicates that this type has given satisfaction when used with tubular boilers. Details of a sample installation, showing the particular features of the side-feed type that have been mentioned in this discussion, are presented in figures 15 and 16, which represent sections through the stoker and boiler. Figure 15 shows the high arch over the grates and the long distance from grates to tube heating surface. The situation of the coal magazines, of the hot-air ducts above the arch, and of the air passages under the coking plates, as well as the ample size of the combustion chamber, are made plain by figure 16.

DETAILED DESCRIPTION OF PLANTS.

In all, 76 plants with side-feed stokers were visited; at 44 the stokers were installed under return tubular boilers, at 30 under water-tube boilers, and at 2 under boilers of both types. The plants ranged in size from 50 to 6,750 horsepower. The coal used came from Illinois, Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia,

and ranged from slack to run of mine. Eleven plants were burning slack. The other 65 used small nut or nut and slack.

Plants with water-tube boilers.—At the 30 plants where stokers of this type were installed under water-tube boilers alone the kind of coal used and the depth of fire were as follows:

TABLE 10.—*Kind of coal and depth of fire at plants with side overfeed stokers under water-tube boilers.*

Kind of coal.	Number of plants.[a]	Average depth of fire.	Kind of coal.	Number of plants.[a]	Average depth of fire.
		Inches.			*Inches.*
Illinois	6	5	Pennsylvania	7	5
Indiana	1	6	West Virginia	4	5
Kentucky	1	7	Miscellaneous	5	6
Ohio	7	5			

[a] One plant used both Ohio and Pennsylvania coal.

At 35 per cent of the plants with side-feed stokers under water-tube boilers the boiler units were 200 horsepower or less. The coal as received burned per square foot of grate per hour ranged from 10 to 41 pounds. The percentage of the rated horsepower developed on average heavy load (the boiler being rated on the basis of 10 square feet of heating surface per horsepower) ranged from 37 to 189. These and other details are summarized in the subjoined table.

TABLE 11.—*Summary of various observations at plants with side overfeed stokers under water-tube boilers.*

Type of boiler.	Kind of coal.	Number of plants.	Furnace draft (inch of water).	Coal burned per square foot of grate surface per hour, average heavy load.	Boiler horsepower developed, average heavy load. (a)	Distance from grate to tube-heating surface.		Distance from front of furnace to front of boiler.	Black smoke.
						Average.	Minimum.		
				Pounds.		*Feet.*	*Feet.*	*Feet.*	*Per ct.*
Babcock & Wilcox	Illinois, Ohio, and West Virginia.	8	0.24	22.6	91	8.5	5.7	(b) 6.9	5.2
Stirling	Illinois, Ohio, Pennsylvania, and West Virginia.	9	.36	23.1	85	9.4	6.5	4.1	2.8
Miscellaneous water tube.	Illinois, Indiana, Kentucky, Ohio, and Pennsylvania.	15	.22	23.7	81	7.9	5.5	(c) 4.1	6.0

[a] Boiler rated on 10 square feet of heating surface per horsepower.
[b] From 7 plants.
[c] From 13 plants.

The average ratio of heating surface to grate surface at these plants was 59.1 to 1, the range being from 33 to 1 to 72 to 1. The grate area of this type of stoker was taken to be equal to the distance

between the coking plates multiplied by the distance from the front of the furnace to the rear of the grates.

Natural draft, supplied by a chimney, was used at most of the plants. The furnace draft varied from 0.10 to 0.35 inch of water, but most of the readings were between 0.15 and 0.25 inch. The draft measurements are summarized below:

TABLE 12.—*Summary of draft measurements at plants with side overfeed stokers under water-tube boilers.*

Type of boiler.	Measurement taken at—	Number of plants at which taken.	Average draft (inch of water).
Babcock & Wilcox	Furnace	7	0.24
	Rear of boiler	7	.43
	Base of stack	2	.58
Stirling	Furnace	8	.36
	Rear of boiler	7	.47
	Base of stack	5	.81
Miscellaneous water tube	Furnace	12	.22
	Rear of boiler	7	.51
	Base of stack	8	.67

Furnace draft, 27 plants, 0. 10 to 0. 53 inch water; average 0. 27 inch. Draft at rear of boiler, 21 plants, 0. 18 to 0. 90 inch; average, 0. 47 inch. Draft at base of stack, 15 plants, 0. 18 to 1. 10 inches; average, 0. 71 inch. The approximate average drafts were as follows: Furnace, 0. 25 inch; rear of boiler, 0. 50 inch; base of stack, 0. 75 inch. These figures show a draft drop of 0. 25 inch of water through the furnace and of 0. 25 inch from boiler to stack.

Details of the observations at plants with side-feed stokers under water-tube boilers are given in Table 13.

TABLE 13.—*Details of observations at plants with side overfeed stokers under water-tube boilers.*

No. of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
90	Illinois	Murphy	5,040		Green County, Ill	Screenings		
91	do	do	500	Washed	Williamson County, Ill	Nos. 2 and 4	$2.85–$3.00	
92	Michigan	do	500	Hocking Valley	Ohio	Slack	1.50	6,000
93	Ohio	do	200	Massillon	do	¾-inch to 1-inch screenings.	1.80	1,455
94	Pennsylvania	do	1,200		West Virginia	Run of mine	2.80	
95	Ohio	do	500	New River	do	Nut and slack		
96	Pennsylvania	do	458			Run of mine	3.00	
97	Illinois	do	2,000	Washed	Carterville, Ill	Nos. 2 to 5	2.45	12,000–15,000
98	do	do	400	do	do	No. 3	2.15	
99	Ohio	do	1,200	Various coals	Ohio	Pea and slack	1.90	6,000
100	do	do	500	Youghiogheny	do	1-inch nut	1.90	
101	do	do	413	do	do	No. 1 nut	1.90	
102	do	do	1,200	Pittsburg	Pennsylvania	Slack	1.52	6,220
103	Pennsylvania	do	306	Westmoreland gas slack	do	do	2.80	
104	Ohio	do	600	Kanawha	West Virginia	Nut and slack	1.75	
105	do	do	200	do	do	do	1.75	
106	do	Detroit	400			do	2.00	2,400
107	Illinois	Murphy	600	Washed	Carterville, Ill	No. 4	2.70	
108	do	do	1,000	do	do	No. 3	2.90	
109	Indiana	do	250	Linton No. 4	Indiana	Nut and slack	2.55	
110	Kentucky	Detroit	400	Straight Creek	Kentucky	do		
111	Ohio	Murphy	1,320	Various coals	Ohio; Pennsylvania	¾-inch screenings	1.50–1.65	
112	do	do	1,200	Pittsburg No. 8	Dillonvale, Ohio	Pea and slack	1.80	
113	do	do	350	Youghiogheny	Pennsylvania	1-inch nut	1.90	
114	Pennsylvania	do	200	Lincoln gas slack	do	Nut and slack	3.50	
115	Ohio	do	1,200	Youghiogheny	do	Nut	2.50	7,300
116	Kentucky	Model	300	Pittsburg	do	Nut and slack		
117	Pennsylvania	Murphy	600			Run of mine; slack		1,880
118	New York	do	6,750	Various coals		1¼-inch screenings	1.93	38,570
119	Michigan	Detroit	300	do		Nut and slack	1.92	1,500

TABLE 13.—*Details of observations at plants with side overfeed stokers under water-tube boilers*—Continued.

No. of plant.	Load.			Rating.							
	Requirement.	Nature.	Character.	Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
				Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
90	Power and heat	Variable	Street railway	24	150–200	24	100–130	23.8	22.8	114	114	5
91	Power, light, and heat	do	Printing office	24	12	24	8	29	24	106	80	5
92	do	Uniform	Factory	24	19	24	19	31.7	31.7	106	106	5
93	do	do	do	10	4.7	10	4.7	22.4	22.4	104	118	4
94	Power	do	Ice plant	24	60	24	25	22.3	20.5	98	104	4
95	Power, light, and heat	do	Lead works	10	2.6	14	2.4	12.4	10.2	44	46	4.5
96	do	Variable	Factory	10.25	6.5			16.3		65	69	4
97	Power and heat	Uniform	Department stores	11	70	12	6	24.7		145	145	5
98	Power, light, and heat	Variable	Factory	9	6	9	4	34	29		133	5
99	Power and light	Uniform	Municipal waterworks	14	15.3	18	10.4	14.6	13.1	50	54	4.5
100	Power, light, and heat	do	Factory	10	7.3	10	7.3	17.4	17.4	68	59	5
101	do	do	do	10	7	10	7	21.9	21.9	68	68	5
102	do	do	do	10.5	15.5	10.5	14	20.6	19.5	73	73	4.5
103	Power and light	do	Refrigeration	24	10	24	8	17	15.3	68	68	4
104	do	do	Union depot	5	6	19	11	33.3	24.5		120	5
105	Power and heat	do	Depot	24	7			12.2			65	4.5
106	Power and light	do	Office building	11	6.75	11	6.75	35	35	123	123	5
107	Power, light, and heat	Variable	Hotel	24	20	24	8	26	18	111	111	5
108	Power and heat	Uniform	Office building	12	14	12	12	33	32	109	80	5
109	Power, light, and heat	do	Hotel	14	7.75			18.5			88	5
110	do	Variable	Brewery	24	11.5			37.4			96	5
111	do	do	Factory	12	24	12	17	14	12	62	62	5
112	do	Uniform	Shops	10	19	10	19	26.4	26.4	90	95	5
113	do	do	Factory	10	8.7	10	8.7	17.4	17.4		100	5
114	do	Variable	Store building	10.5	3.5			16.7	16.7	69	86	4
115	do	Uniform	Hotel	24	20	24	20		14	46	46	4.5
116	do	do	Refrigeration	24	8.8			27.7			98	5
117	do	do	Factory	11	7			17.2		78	71	4
118	Power and light	do		8	80	8	80	30	30	104	92	4
119	Power and heat	do		10.5	5	10.5	5	20.5	20.5	63	63	5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 13.—*Details of observations at plants with side overfeed stokers under water-tube boilers*—Continued.

No. of plant.	Stoking.		Boilers.									
	Thickness of fire (inches).	Frequency of cleaning fire.	Type.	Size.	Number installed.	Number used to carry—		Builders' rated horsepower.	Horsepower.[a]	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
						Average heavy load.	Average light load.					
90	6	Continuous	Babcock & Wilcox	198 4″ tubes, 3 36″x 20¼′ drums	12	(b)	(b)	420	420	4,200	0	160
91	3.5–4	Variable	do	90 4″ x 18′ tubes, 2 30″ drums.	2	1	1	250	189	1,890	0	140
92		Continuous	do	Small boiler, 72 4″ x 18′ tubes.	3	2	2	200, 150	200, 150	2,000, 1,500	0	130
93	4	do	do	108 4″ x 18′ tubes	1	1	1	200	227	2,265	0	100
94	3–6	do	do	154 4″ x 18′ tubes, 1 42″ x 20⅓′ drum.	4	4	2	300	318	3,180	0	145
95	4–6	do	do	126 4″ x 18′ tubes	2	1	1	250	264	2,640	0	95
96	(b)	do	do	1–126 4″ x 18′ tubes, 1–108 4″ x 18′.	2	2		250, 208	264, 226	2,640, 2,260	0	85
97	6–8	do	Stirling	2–181 3¼″ tubes, 3–403 3¼″ tubes	5	4	1	250, 500	250, 500	2,500, 5,000	0	100
98	4–6	do	do	181 3½″ tubes, 3 36″ drums	2	1	1	200			0	150
99		do	do		4	3	2	300	322	3,223	0	145
100	5–6	do	do		2	2	2	250	214	2,135.	0	100
101	5–6	do	do		1	1	1	413	413	4,130	0	100
102	4	do	do		4	3	3	300	300	3,000	0	150
103	6	do	do	168 3¼″ tubes	1	1	1	306	305	3,050	0	130
104	4–6	do	do	192 3½″ tubes	3	2	2	200			0	110
105	4–6	do	do	96 3½″ tubes	2	2		100			0	100
106	4	do	do	176 3½″ tubes	2	1	1	200	200	2,000	0	115
107	3–4	do	Aultman & Taylor	144 4″ x 18′ tubes, 2 36″ drums.	2	1	1	300	300	3,000	0	150
108	3–6	Variable	Heine	113 3½″ x 16′ tubes, 2 30″ x 16′ drums.	4	2.5	2	250	184	1,840	0	100
109	6	Continuous	Erie City		2	2	2	125			0	115
110	6–8	do	Henry Vogt		2	1		200			0	105–120
111		do	Heine; Stirling		6	6	6	140, 380	140, 380	1,402, 3,795	0	110
112	5	do	McNaull	100 4″ x 17′ tubes	6	4	4	200	210	2,095	0	200
113	5–6	do	Hazelton		1	1	1	350			0	100
114	4–6	do	National	72 4″ x 14′ tubes	2	2	2	100	120	1,200	0	100
115		2 times in 12 hours	Aultman & Taylor		3	2	2	400	402	4,022	582	150
116	4–5	Continuous	Henry Vogt		2	1	1	150			0	100
117	4–6	do	Heine; Edgemoor	2–67 3½″ x 18′ tubes, 1–138 4″ x 18′ drums.	3	2	1,2	150, 300	110, 300	1,100, 3,000	0	110–115
118	6–10	Once in 8 hours	Standard	192 4″ x 18′ tubes	15	12	12	450	402	4,020	0	110
119		Continuous	Atlas		2	2	2	150	150	1,500	0	110

[a] Boiler rated on 10 square feet of heating surface per horsepower.

[b] Variable.

TABLE 13.—*Details of observations at plants with side overfeed stokers under water-tube boilers*—Continued.

No. of plant.	Furnaces.									
			Dimensions (feet).							
	Number.	Grate area per boiler (square feet).	Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance from grates to coking arch or heating surface.		Height of arch at rear of furnace (H).
			Average (A).	Minimum (B).				At front of furnace (F).	At rear of furnace (G).	
90	24	70	10	6.5	5	7	9	3.9	.....	3.9
91	2	35	9	5.5	5	7	8.8	3.75	3.75	.....
92	3	36,25	8,8.5	5.5	5,6	5,6	4	4	4	.....
93	1	42	9.5	6.5	7	6	6.6	5	5	.....
94	4	56	8.5	5.5	8	7	7.2	6.1	6.1	.....
95	2	42	8	6	7	6	6.5	4.8	.....	4.8
96	2	42,36	[a]8,7	[a]5.5,4.5	6	[a]6,7	6	4.4	4.4	.....
97	8	38.5,77	14	10.5	5.6	7	9	4.5	4.5	.....
98	2	39	7.5	4.5	6.5	6	2	5	5	.....
99	8	50	11	9	5	5	6.6	4.5	4.5	5.5
100	2	42	7	3.5	7	6	0	5	5	5
101	1	64	7	3.5	8	8	2	6.5	6.5	6.5
102	4	48	8	5	8	6	3	6	6	6
103	1	49	14.5	11	7	7	7.5	5.25	5.25	.....
104	3	36	8.5	6	6	6	4.5	4.8	.....	4.8
105	2	24	9.5	6.5	4	6	4.5	3.5	.....	3.5
106	2	35	5.5	3.5	6.75	5.25	0	4.8	.....	4.8
107	2	49	20	16.5	7	7	9	5.25	5.25	.....
108	8	30	9	6.5	3	5	0	2.75	.....	2.75
109	2	30	.....	.....	5	6	1.25	.....	.....	.....
110	2	25.7	.....	.....	4.7	5.5	0	.....	.....	.....
111	8	42,63	[b]9,6.5	[b]7,3	[b]6,7	[b]7,4.5	0	[b]—,3.3	[b]—,3.3	.....
112	6	36	9	6	6	6	6	5	5	.....
113	4	100	8	.....	5	5	.....	.....	.....	.....
114	2	20	7	4.75	4	5	5.3	3.25	3.25	.....
115	3	59.5	10.5	7.5	7	8.5	9	6.5	6.5	.....
116	2	26.5	.....	.....	4.4	6	0	.....	.....	.....
117	3	25,49	[b]7.5,8	5.5	[b]5,7	[b]5,7	0	3.9	3.9	.....
118	15	56	9	6	8	7	8.5	6	6	.....
119	2	23.2	3.5	3	5.25	4.4	0	5.5	5.5	.....

[a] First dimension applies to small boiler.

[b] First dimension applies to Heine boiler.

TABLE 13.—*Details of observations at plants with side overfeed stokers under water-tube boilers*—Continued.

No. of plant.	Draft.						Smoke records.						
	Kind.	Readings (inches of water).				Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for one hour (minutes).			Average percentage of black smoke.	Load during observations.
		Furnace.	Rear of boiler.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
90	Chimney	0.18–0.27	0.44–0.54			Dampers open	3	160	0.5	0	0	14.1	Average.
91	do	.18	.50			Ash-pit doors open, dust doors cracked.	1	60	0	0	48	3.3	Light.
92	do	.17– .19	.31– .40		0.56	Dust-pit doors open	1	60	0	2	56	2.2	Average.
93	do	.09– .12	.16– .19	0.29–0.31			1	300	0	1	56	1.7	Do.
94	do	.25– .30	.44– .45	.70– .75		Ash and dust-pit doors open; damper partly closed.	1	60	0	0	56	.8	Light.
95	do	.37	.50			Damper and ash-pit doors open	(a)	(b)	0	0			Do.
96	do	.37, .42	.55, .58		.60	Dampers open; ash-pit doors cracked.	2	80	0	1	27	9.1	Heavy.
97	do	.20	Lower rear, .35		.75	Door in stack open	3	183	0	0	44	3.5	Light.
98	do						1	77	0	2	50	4.9	Do.
99	do	.18– .24	.32– .38	.22– .34	.54	Dampers open	1	45	0	0	57	.9	Average.
100	do	.18– .28	Lower rear, .56– .64				2	120	0	2	49	5	Do.
101	do	.18– .36	Lower rear, .34– .58		.76		2	120	0	1	56	1.8	Do.
102	do	.11– .18	Lower rear, .40– .60		.90		1	60	0	0.5	53	2.5	Do.
103	do	.53	Lower rear, .60	.90		Damper open	1	46	0	0	57	1.3	Heavy.
104	do	.15		.75		do	(a)	(b)	0	0			Light.
105	do	.10		.45– .50		do	(a)	(b)	0	0			Heavy.
106	do		Lower rear, .45	.90	1.10	Dampers open; thin fire	(a)	(b)					Average.
107	do	.12		.43		Damper open	3	211	0	0	60	0	Do.
108	do	.08– .17	.90	1.26		Dampers open	5	333	0	0	56	1.4	Do.
109	do						1	60	0	0		12.7	Light.
110	do	.34	.39– .45	.64		Damper and ash-pit doors open	2	115	0	4	48	12.5	Heavy.
111	do	.12– .30		.65– .74			1	60	0	0	44	7.7	Average.
112	do	.14– .25		.26– .34	.55–.60	Dampers open	1	60	0	.5	55	2.5	Do.
113	do	.12– .15			.18		2	120	0	0	60	0	Do.
114	do	.13– .15			.65	Dampers partly closed	1	30	0	0	30	7.7	Heavy.
115	do	.30– .48	.53– .67		1.10	Ash-pit doors open	1	600	0	0	49	5.7	Average.
116	do	.18	.43		.70	Damper partly closed	1	110	1	1	43	7	Heavy.
117	do	.20– .30	.30– .40		.65	Dampers open; heavy fire	1	60	0	0	35	7.2	Light.
118	do	.20– .29	.25– .56		.92–1		1	60	0	0	39	8.3	Average.
119	do	.22– .26	.39– .49		.56		1	30	0	0	30	5	Do.

(a) Several.

(b) Various lengths.

TABLE 13.—*Details of observations at plants with side overfeed stokers under water-tube boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
90	4	.....	.....	0	203	*a* 16	201	Coal as received contains 16 to 20 per cent ash; 11,000 to 11,500 B. t. u. per pound. Steam pressure regulated by opening and closing ash-pit doors. Plant runs in connection with storage batteries which are used to assist in carrying peak loads. Stack smoked considerably, 10 to 20 per cent black.
91	5	.....	.....	1	110	*a* 5	19.6	
92	0	0	.....	0	105	4 x 4	16	
93	50	.....	.....	4	71	3 x 3	9	
94	35	.....	.....	0	150	*a* 12	113.5	Automatic regulator on main damper in breeching. Stack reported bad at times on heavy load.
95	26	.....	.....	1	165	*a* 5.5	23.7	
96	3	.....	.....	1	122	*a* 5.5	23.7	Automatic regulator on main damper.
97	40	.....	.....	1	305	*b* 13 x 6	70.3	One 250-horsepower boiler carries the light load; three 500-horsepower and one 250-horsepower the heavy load. Try to carry draft of about 0.25 inch water in furnace. Run with dust-pit doors three-quarters open and ash-pit doors half open.
98	12	4 x 4.5	Near stack.....	0	125	*a* 5	19.6	Coal as received contains about 12,000 B. t. u. per pound and 7 per cent ash. Furnace too large for light load. On light load run with damper half closed, ash-pit and dust-pit doors closed, furnace door three-quarters closed. No draft readings taken on account of these conditions.
99	9	.....	.....	1	140	6 x 6	36	Wet coal banks on grates and has to be poked down, producing smoke.
100	0	0	.....	0	108	*a* 2.5	4.9	Two similar stacks, resting on rear of boilers. Smoke average is from both stacks.
101	0	0	.....	0	100	*a* 3	.06	Stacks rest on rear of boilers.
102	15	.....	.....	0	152	*a* 6.5	33.2	Smoke observation taken when carrying furnace draft of 0.15 inch water. With furnace draft reduced to 0.07 inch stack smoked continuously, 20 to 40 per cent black.
103	35	.....	.....	1	150	*a* 8	50.24	Automatic regulator attached to main damper.
104	3	.....	.....	0	125	*a* 4	12.56	Smoke observations include some readings 10 and 20 per cent black. Total length of Murphy and Stirling arch, 9 feet.
105	10	.....	.....	0	80	2 x 2	4	Draft assisted by ½-inch steam pipe entering breeching. Smoke observations include some readings 10 and 20 per cent black. Total length of Murphy and Stirling arch, 10 feet.
106	11	.....	.....	0	252	*a* 4	12.56	Smoke observations include a great many readings 20 per cent black and several 60, 80, and 100 per cent black. Stoker does not distribute the coal evenly along grate, and fire has to be poked down.
107	20	4 x 4	Near stack.....	1	127	*a* 6	28.3	Coal as received runs about 12,000 B. t. u. per pound. A gas-mixing pier is in combustion chamber, also 16-inch projections built on bridge wall to deflect gases inward. Gases cross the tubes four times. Very hot fire.
108	11	10 x 4	.....do.....	0	305	*a* 7	38.5	Coal as received runs about 12,000 B. t. u. per pound. Arch 5 feet 9 inches long. C tile on lower row of tubes. Run with ash-pit doors open.

109	18	..	.....	1	125	*a* 4	12.56	
110	18	.	.....	0	.....	.....	.....	Fired occasionally through furnace door.
111	5	.	.....	1	125	*a* 6.5	33.2	Coal as received runs about 12,700 B. t. u. per pound and 10 to 14 per cent ash. One stoker per Heine boiler; two stokers per Stirling boiler. U tile on lower row of tubes of Heine boiler. About half as much coal burned per furnace under Stirling boilers as under Heine boilers. Stirling boilers have poor draft.
112	22	.....	.....	2	110	*a* 7.1	40	Boiler baffled vertically.
113	0	0	.....	0	66	*a* 4	12.56	Stacks rest on top of boiler.
114	8	.....	.....	0	125	*a* 5	19.6	Automatic regulator attached to main damper.
115	11	.....	.....	0	175	*a* 7	38.5	
116	2	.....	.....	1	105	*a* 3.5	9.6	Stack smokes sometimes from 20 to 30 per cent black for ten to fifteen minutes.
117	5	.....	.....	0	120	*a* 5	19.6	Either the two small boilers or the large one will carry the light load. Edgemoor boiler is baffled like Heine. U tile on lower row of tubes. Automatic regulator on main damper.
118	0	.....	.....	2	250	*a* 16	201	Fires sliced often. Rubbish burned also at this plant.
119	12	.....	.....	1	95	3.3 x 3.3	11.1	Smoked considerably, 10 per cent black.

a Diameter.

b Ellipse.

Plants with return tubular boilers.—Side overfeed stokers were installed under return tubular boilers at 48 plants, with rated boiler capacity varying from 50 to 180 horsepower. At two of these plants the stokers were set in a Dutch oven. The kinds of coal burned and the thickness of fire were as follows:

TABLE 14.—*Kind of coal and depth of fire at plants, with side overfeed stokers under return tubular boilers.*

Kind of coal.	Number of plants.	Average depth of fire.	Kind of coal.	Number of plants.	Average depth of fire.
		Inches.			*Inches.*
Illinois	7	5	Pennsylvania	11	5
Indiana	3	4	West Virginia	8	6
Kentucky	5	4	Miscellaneous	8	5
Ohio	6	5			

Other details given in Table 15 regarding the setting and operation of side-feed stokers at these plants may be briefly summarized thus:

Draft through fire, 0.17 inch; coal as received burned per square feet of grate surface per hour, average heavy load, 20.6 pounds; percentage of rated boiler horsepower developed, average heavy load (boiler rated on 10 square feet of heating surface per horsepower), 90; average distance from grates to tube heating surface, 14.5 feet; average vertical distance from clinker grinder to coking arch, 3.75 feet; per cent of black smoke, 5.6. Approximate draft averages gave a furnace draft of 0.15 inch and a drop through the boiler of 0.25 inch. The drop from the boiler to the stack averaged 0.20 inch.

Details of the observations at plants with side-feed stokers under return tubular boilers are given in Table 15

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers.*

No. of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
120	Illinois	Murphy	1,080	Washed	Marion County, Ill.	No. 2	$2.90	
121	do	do	640		Illinois; Indiana	Screenings	1.80–2.35	
122	do	do	360	Steam nut	Benton, Ill.	Through a 3-inch screen	2.35	
123	do	do	320	Carterville	Illinois	Nos. 2 and 3, mixed		
124	do	do	250	Carterville, washed	do	No. 3	2.15	
125	do	do	250		do	No. 3 nut and screenings.		
126	do	do	176	Carterville, washed	do	No. 3	2.80	
127	Indiana	do	400	Linton	Indiana	No. 4	2.35	
128	do	Detroit	195		do	Nut and slack		
129	Kentucky	do	600		Western Kentucky	Pea and slack		
130	do	do	450		do	do		
131	do	do	300		do	Nut and slack		
132	do	do	150		do	Pea and slack		
133	Ohio	Murphy	100	Laurel; Jellico	Kentucky	Nut and slack	2.00	
134	do	do	600	Pittsburg No. 8	Dillonvale, Ohio	Pea and slack	2.00	
135	do	do	600	do	Ohio	Slack	2.05	7,300
136	do	do	500	do	do	do	2.35	5,500
137	do	do	450	do	Dillonvale, Ohio	Pea and slack	2.00	5,100
138	do	do	300	Youghiogheny	Ohio	1-inch nut	1.90	
139	New York	do	874	Pittsburg	Elk County, Pa.	Slack	2.40	6,000
140	Kentucky	Detroit	600		Pittsburg, Pa.	Nut and slack		
141	Pennsylvania	Murphy	405	Clearfield	Pennsylvania	Run of mine	2.80	
142	Ohio	do	360	Pittsburg	do	Nut and slack	1.87	
143	do	do	320	do	do	do		
144	Pennsylvania	do	300	Westmoreland gas slack	do	Slack	3.00	
145	Ohio	Detroit	300	Pittsburg	do	do	1.80	1,200
146	New York	Murphy	300	Rochester; Pittsburg; Reynoldsville.	do	1½-inch nut	2.55	2,100
147	Ohio	do	200	Pittsburg	do	Nut and slack		
148	Pennsylvania	do	150		do	do		
149	Ohio	do	50	Pittsburg	do	do		
150	do	do	1,000	Kanawha	West Virginia	do	2.00	
151	do	do	790	do	do	do	2.00	
152	do	do	750	do	do	do	1.69	
153	Pennsylvania	do	445	Gas slack	do	Slack	2.55	
154	Michigan	Detroit	350	Pittsburg No. 8; Thacker.	Ohio; West Virginia	Nut and slack	2.60	2,500
155	Ohio	Murphy	300	Kanawha	West Virginia	do	1.90	2,730
156	Michigan	Detroit	250	Red Jacket	do	do	2.70	900

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
157	Kentucky	Detroit	140		West Virginia	Run of mine; pea and slack.		
158	Pennsylvania	Murphy	1,000	Gas slack			$3.05	
159	do	do	450			Run of mine		
160	Ohio	do	250			Nut and slack	1.90	
161	Michigan	do	200	Various coals		Slack	2.00	
162	Pennsylvania	do	180			Run of mine		
163	do	do	179			Slack	3.30	
164	Ohio	Detroit	150	Cedar Point		Nut and slack	1.70	
165	do	Murphy	150	Various coals		Slack	1.85	1,200

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Load.			Rating.							
				Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
	Requirement.	Nature.	Character.	Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
120	Power, light, and heat	Uniform	Department store	11	33	11	39	26	25	110	143	5
121	do	Variable	Office building	18	16	18	13	21	19	95	77	5
122	do	Uniform	Hotel	18	10	18	8	31	28	134	123	5
123	do	Variable	do	24	14	24	12.5	24.3	23	124	146	5
124	do	do	Factory	9	7	9	6	23.5	21.9	106	123	5
125	do	Uniform	Office building	17	6	17	6	17.7	17.7	75	88	5
126	do	do	do	18	8	12	5	29.6	28.6	189	214	5
127	do	do	Store building	9.5	11	9.5	9.5	23.2	21.6	95	116	5
128	do	do	School building	24	10	16	4.5	17.4	17.4	109	81	5
129	do	do	Ice plant	24	20	24	16	37	33.3	83	83	5
130	Power and light	do	do	24	20	24	18	41.3	39	105	111	5
131	Power and heat	do	Factory	10	3	10	3	33.3	33.3	75	80	5
132	do	do	Pottery	11	1.6	11	1.6	10	10	37	39	5
133	Power, light, and heat	do	Printing office	9.5	2.5	9.5	1.4	21	17.8	85	105	5
134	do	do	Office building	14	8	.....	.....	17.3	.....	71	85	4.5
135	do	do	Store and office building	17	11.6	17	9.2	19	15.5	61	68	5
136	do	do	Office building	12	10	12	9	25.3	24	104	89	5
137	do	do	do	12	8	12	8	14.8	14.8	64	66	4
138	do	do	Factory	10	4.4	10	4.4	17.6	17.6	72	88	5
139	Power	do	Refrigeration	12	15	.....	.....	20	.....	107	107	4
140	Power and light	Variable	Apartment house	24	10.3	24	9	17.4	16.3	58	57	5
141	Power, light, and heat	Uniform	Factory	11	6.7	.....	.....	13	.....	65	75	4
142	do	Variable	Office building	18	7	18	4.5	15.6	12.8	64	65	5
143	do	do	Brewery	12	10	24	16	16.7	15	.....	104	5
144	Power and heat	Uniform	Mill	11	10	11	7.8	27.6	24.5	182	152	4
145	Power and light	do	Factory	10	5.5	10	5.5	14.7	14.7	94	82	4.5
146	Power, light, and heat	do	Hotel	24	6	24	6	14	14	79	83	4
147	do	Variable	Brewery	12	5.5	24	9	14	12.7	.....	93	5
148	Power	Uniform	Factory	10	2.8	10	2.2	14	12.5	73	93	4

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Load.			Rating.								
	Requirement.	Nature.	Character.	Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
				Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
149	Heat	Variable	Dye works	11	2	11	1	16.2	12	119	146	5
150	Heat and light	do	Brewery	11	12.9	11	9.1	15.9	14.8	64	84	4.5
151	Power, light, and heat	Uniform	Department store	10	9	10	6	19	16.4	71	62	5
152	do	do	Office building	16	8	16	4	20	20	72	67	5
153	Power and heat	do	Factory	10	13.4	10	10	25.5	22.7	138	147	5
154	Power, light, and heat	do	Hotel	13	4.5	13	4.5	23.5	23.5	86	88	4.5
155	do	do	Mill	24	8.5	24	8.5	14.2	14.2	47	53	4.5
156	do	do	Office building	10	2.6	10	2	23.6	20.9	84	92	4.5
157	do	do	do	24	2	.....	.....	12.4	.....	42	60	5
158	do	do	Factory	12	28	12	20	28	24	131	117	4
159	Power	do	Ice plant	24	30	24	22.5	25.3	22.1	92	139	4
160	Power, light, and heat	do	Factory	14.5	3.5	10	6	20.7	20.4	79	96	5
161	Power and heat	do	do	24	6.7	10	1.6	11.2	.....	40	62	4.5
162	do	do	Mill	10.5	3.4	10.5	3.4	14.4	14.4	67	80	4.5
163	do	do	do	9.5	3	9.5	3	15.8	15.8	73	88	4
164	Power, light, and heat	do	Library	13.5	5	13.5	3	25.1	23	81	99	5
165	do	Variable	Shops	10	4	10	4	22.2	22.2	89	107	5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Stoking.		Boilers.									
	Thickness of fire (inches).	Frequency of cleaning fire.	Type	Size.	Number installed.	Number used to carry—		Builder's rated horsepower.	Horsepower boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
						Average heavy load.	Average light load.					
120	4	3 times in 24 hours	Return tubular	72″ x 20′, 56 4½″ tubes	9	7	9	120	155	1,550	0	100
121	3–4	Continuous	do	1 48″ x 14′, 32 3½″ tubes; 6 48″ x 16′, 32 3½″ tubes; 2 42″ x 16′, 28 3½″ tubes.	9	7	5	60, 65, 75	49, 55	490, 550	0	100
122	3–6	do	do	66″ x 16′, 42 4″ tubes	4	2	2	90	83	830	0	120
123	4–5	3 to 4 times in 24 hours	do	60″ x 16′, 48 4″ tubes	4	2	2	80	94	940	0	90
124	6	Continuous	do	78″ x 19′, 84 3″ tubes	2	2	2	125	147	1,470	0	110
125	3–4	do	do	54″ x 16′, 48 4″ tubes	3	2	2	80	94	940	0	85
126	5	do	do	1 66″ x 16′, 54 4″ tubes; 1 60″ x 18′, 42 4″ tubes.	2	1	1	93, 83	106, 94	1,060, 935	0	85, 90
127	4	do	do	3 66″ x 16′, 64 4″ tubes; 1 66″ x 14′, 72 3½″ tubes.	4	4	4	100	126, 109	1,260, 1,085	0	80
128	3	do	do	60″ x 20′, 5 12″ tubes	3	3	2	65	51	505	0	70
129	4	do	do	78″ x 18′, 90 4″ tubes	3	2	2	200	200	2,000	0	100
130	3	do	do	72″ x 18′, 72 4″ tubes	3	2	2	150	159	1,590	0	105
131	4	do	do	72″ x 18′, 72 4″ tubes	2	1	1	150	159	1,590	0	90
132	4–6	do	do	60″ x 18′, 72 4″ tubes	1	1	1	150	159	1,590	0	80
133	5	3 times in 10 hours	do	66″ x 18′, 56 4″ tubes	1	1	1	100	124	1,240	0	80
134	.....	Continuous	do	72″ x 18′, 92 3½″ tubes	4	2	.....	150	178	1,785	0	100
135	4	Once in 17 hours	do	78″ x 20′, 84 4″ tubes	3	2	2	200	225	2,250	0	120
136	4	Continuous	do	60″ x 18′, 48 4″ tubes	4	3	3	125	107	1,065	0	110
137	5	do	do	3 60″ x 16′, 48 4″ tubes; 1 72″ x 18′, 90 3½″ tubes.	4	4	4	100, 150	95, 176	950, 1,760	0	90–100
138	5–6	do	do	66″ x 18′, 54 4′ tubes	3	2	2	100	122	1,220	0	100
139	4–5	do	2 return tubular 3 Babcock & Wilcox	2 60″ x 18′, 72 4″ tubes; 1 90 4″ x 16′ tubes; 1 108 4″ x 16′ tubes; 1 120 4″ x 16′ tubes.	5	3	.....	125, 200 224	158, 168 201, 224	1,580, 1,675 2,010, 2,235	0	160
140	4	do	Return tubular	72″ x 18′, 70 4″ tubes	4	2	2	150	147	1,470	0	100
141	4–6	do	do	3 60″ x 18′, 36 4½″ tubes; 1 72″ x 18′, 60 4½″ tubes.	4	4	.....	85, 150	108, 146	1,080, 1,460	0	100
142	6–7	3 times in 24 hours	do	60″ x 18′, 48 4″ tubes	3	2	2	120	122	1,220	0	95
143	4	Continuous	do	62″ x 16′	4	4	4	80	.....	.....	0	90
144	4–6	do	do	72″ x 18′, 45 5″ tubes	2	2	2	150	125	1,250	0	120
145	3–5	do	do	60″ x 16′, 44 4″ tubes	3	3	3	100	87	870	0	100

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Stoking.		Boilers.									
	Thickness of fire (inches).	Frequency of cleaning fire.	Type.	Size.	Number installed.	Number used to carry—		Builder's rated horsepower.	Horsepower boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
						Average heavy load.	Average light load.					
146	6	Continuous	Return tubular	72″ x 16′, 92 3½″ tubes	2	1	1	150	159	1,585	0	90
147	4	do	do	72″ x 18′	2	2	2	100			0	90
148	3–4	do	do	60″ x 16′, 36 4½″ tubes	2	2	2	75	96	960	0	65
149	(*a*)	3 to 4 times in 11 hours	do	60″ x 16′, 18 6″ tubes	1	1	1	50	61	610	0	45
150	8–10	5 times in 24 hours	do	4 72″ x 16′, 84 4″ tubes; 4 72″ x 16′, 72 4″ tubes.	8	5	4	125	175, 155	1,750, 1,550	0	85
151	6–8	Once in ten hours	Return tubular; Heine water-tube.	1 72″ x 18′, 70 4″ tubes; 1 113 3½″ x 16′; 2 87 3½″ x 16′.	4	4	2	{140, 200, 250	166, 142 184	1,560, 1,420, 1,840	0	110
152	6	6 times in 24 hours	Return tubular	72″ x 16′, 70 4″ tubes	5	2	1	150	138	1,380	0	80
153	3–4	Continuous	do	4 60″ x 16′, 44 4″ tubes; 1 72″ x 18′, 45 5″ tubes.	5	4	4	80, 125	87, 127	870, 1,270	0	80
154		do	do	78″ x 18′, 82 4″ tubes	2	1	1	175	180	1,800	0	110
155	3–5	do	do	1 72″ x 18′, 72 4″ tubes; 1 72″ x 18′, 92 3½″ tubes.	2	2	2	150	158, 179	1,576, 1,785	0	100
156	4–5	do	do	72″ x 16′, 70 4″ tubes	2	1	1	125	137	1,372	0	80
157	5–6	do	do	54″ x 18′, 36 4″ tubes	2	1	1	70	80	800	0	80
158	6	do	do	2 72″ x 20′, 60 4″ tubes; 3 72″ x 20′, 60 4½″ tubes.	5	5	5	200	168, 184	1,680, 1,835	0	115
159	4	do	do	78″ x 20′, 86 4″ tubes	3	3	3	150	226	2,260	0	95
160	4	do	do	1 72″ x 18′, 94 4″ tubes; 1 60″ x 16′, 47 4″ tubes.	2	2	2	150, 100	209, 93	2,085, 930	0	95
161		do	do	72″ x 16′, 84 3½″ tubes	2	2	1	100	158	1,575	0	105
162	6	do	do	60″ x 18′, 36 4½″ tubes	2	2	2	90	108	1,080	0	100
163	6	do	do	1 72″ x 18′, 45 5″ tubes; 1 54″ x 14′, 42 3½″ tubes.	2	2	2	123, 56	144, 74	1,440, 735	0	90
164	4–6	do	do	60″ x 16′, 46 4″ tubes	2	2	1	75	91	910	0	85
165	4	2 times in 10 hours	do	72″ x 18′, 74 4″ tubes	1	1	1	150	180	1,802	0	100

a Variable.

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Furnaces.									
	Number.	Grate area per boiler (square feet).	Dimensions (feet).							
			Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance from grates to coking arch or heating surface.		Height of arch at rear of furnace (H).
			Average (A).	Minimum. (B).				At front of furnace (F).	At rear of furnace (G).	
120	9	33	21	18	5.5	6	0	4	4	.....
121	9	14	16, 18	14, 16	3.5	4	0	2.7	2.7	.....
122	4	18	16	14	4.5	4	0	3.5	3.5	.....
123	4	24	17	14	4	6	0	3	3	.....
124	2	33	17.5	14.5	5.5	6	0	4.5	4.5	.....
125	3	20	16	13.5	4	5	0	3	3	.....
126	2	30	15, 17	12, 14	5	6	0	2.25	2.25	.....
127	4	25	15.5, 13.5	13, 11	5	5	0	4	4	.....
128	3	16	20	18	4	4	0	.....	.....	.....
129	3	22.5	18	15.5	5	4.5	0	.....	.....	.....
130	3	20.3	18	15.5	4.5	4.5	0	.....	.....	.....
131	2	21.8	18	16	4.7	4.6	0	.....	.....	.....
132	1	29.3	18	15	5.3	5.5	0	.....	.....	.....
133	1	25	17	15	5	5	0	4	.....	4
134	4	33	17.5	14.5	5.5	6	0	3.75	3.75	.....
135	2	36	19.5	17	6	6	0	4.3	4.3	.....
136	4	22	17.5	15.5	5.5	5	0	4	4	.....
137	4	20, 30	15, 17	13, 14.5	4, 5	5, 6	0	3.2, 3.5	3.2, 3.5	.....
138	3	25	17.5	15.5	5	5	0	4	4	.....
139	5	36, 45	15, 8	12.5, 5	6	6, 7.5	0, 6	4, 4.25	4, 4.25	.....
140	4	24.75	18	15.5	5.5	4.5	0	.....	.....	.....
141	4	22.5, 27	18	15.5, 15	4.5	5, 6	0	3.5, 4	3.5, 4	.....
142	3	25	17	15	5	5	0	3.4	.....	3.4
143	4	25	15	13	5	5	0	3.4	3.4	.....
144	2	33	17.5	14.5	5.5	6	0	4	4	.....
145	3	25	15.5	13.5	5	5	0	3.1	3.1	.....
146	2	36	15	12	6	6	0	3.5	3.5	.....
147	2	33	17	14	5.5	6	0	4	.....	4
148	2	20	15.5	13	4	5	0	3.2	3.2	.....
149	1	22.5	15.5	13.5	4.5	5	0	3.75	.....	3.75
150	8	33, 27.5	16, 13	15.5, 12	5.6	6, 5	0	3.8	3.8	.....

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Furnaces.									
	Number.	Grate area per boiler (square feet).	Dimensions (feet).							
			Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance from grates to coking arch or heating surface.		Height of arch at rear of furnace (H).
			Average (A).	Minimum (B).				At front of furnace (F).	At rear of furnace (G).	
151	4	30–39, 33	6, 6, 16	4.5, 4.5, 13.5	6, 6, 5.5	5, 6.5, 6	0	4.25, 4.25, 4	.....	4.25, 4.25, 4
152	5	25	15.5	13	5	5	0	4	.....	4
153	5	25, 30	16, 18	13.5, 15	5	5, 6	0	4	4	.....
154	2	29.4	17	15	5.7	5.25	0	4.3	.....	.....
155	2	25	17.5	15.5	5	5	0	4	4	.....
156	2	22	16	14	4.4	5	0	3.8	.....	.....
157	2	13.5	18	16	3	4.5	0	.....	.....	.....
158	5	30, 36	26, 26.5	23.5	6	5, 6	6.5	4.3	4.3	.....
159	3	33	19.5	16.5	5.5	6	0	4.4	4.4	.....
160	2	33, 25	17, 16	14	5.5, 5	6, 5	0	4.2, 4	.....	4.2, 4
161	2	25	15	13	5	5	0	.....	.....	.....
162	2	22.5	18.5	16	4.5	5	0	3.5	3.5	.....
163	2	25, 15	20.5	19, 18	5	3, 5	4.5	3.9	3.9	.....
164	2	17.7	15	13	4	4.4	0	2.2	.....	.....
165	1	36	17	15	6	6	0	4.5	4.5	.....

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Kind.	Draft. Readings (inches of water). Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.	Conditions under which readings were taken.	Smoke records. Number of observations.	Total length of observations (minutes).	Average for one hour (minutes). 100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.	Average percentage of black smoke from observations.	Load during observations.
120	Chimney..	0.08-0.12	[a] 0.22	.....	0.31-0.68	.....	Furnace doors cracked; pit doors and dampers open.	4	237	0	0	32	5.6	Average.
121	...do.....	.08- .12	.....	0.38-0.48	.52- .68	.....	Dust pit and dampers open..	1	61	0	0	57	1	Light.
122	...do.....	.08- .12	.....	.....	.85	.....	Dampers and ash-pit doors open; thin fire.	2	90	1	1	30	12.1	Do.
123	...do.....	.07- .08	.....	.34- .35	.58	.....	Dampers and ash-pit doors open.	2	90	1	1	48	15.3	Average.
124	...do.....	.30	.....	.....	.46	.....	Dampers partly closed; thin fire; dust doors three-fourths open.	1	60	2	3	22	16.2	Light.
125	...do.....	.10 -.12	.....	.46- .48	.....	.....	Dampers and pit doors open.	1	40	0	0	.....	.....	Average.
126	...do.....	.22	.....	.....	.46	.....	Damper and ash-pit doors open.	1	30	0	0	44	2.7	Do.
127	...do.....	.11- .14	.....	.....	.....	0.64	Dampers open; ash and dust-pit doors closed.	2	90	2	4	42	17.7	Light.
128	...do.....	.16- .18	.....	.....	.28	.....	Dampers and pit doors open; thin fire.	1	30	0	0	37	7	Do.
129	...do.....	.36	.....	.63- .65	.....	.....	Dampers open.....	1	40	0	0	0	20	Average.
130	...do.....	.10- .13	.....	.....	.46- .48	.....	Dampers open; thin fire....	1	55	0	0	0	30	Do.
131	...do.....	.25	.....	.37	.....	.48-.52	Damper open.....	1	60	0	0	50	1.4	Do.
132	...do.....	.09	.....	.....	.36	.....	.....do.....	1	60	0	1	57	1.7	Do.
133	...do.....	.18	.....	.....	.35	.....	Damper and ash pit doors open.	2	60	0	0	60	0	Heavy.
134	...do.....	.20- .27	.....	.....	.50- .65	1.10	.....	[b]	[c]	0	0	57	1.5	Light.
135	...do.....	.28- .37	.....	.52- .70	.....	.....	Damper open; thin fire.....	1	240	0	0	59	.3	Average.
136	...do.....	.07- .11	.....	.41	.92	.....	.....	1	240	0	0	57	1.2	Do.
137	...do.....	.10- .16	.....	.38- .45	.84	.90	.....	[b]	[c]	0	0	0	10	Do.
138	...do.....	.06- .08	.....	.09- .19	.....	.....	.....	2	120	0	0	60	0	Do.
139	...do.....	.09- .15	.12- .22	.....	.....	.....	Ash-pit doors open.....	1	60	0	0	58	.7	Heavy.
140	...do.....	.33- .34	.....	.....	.42	.....	Dampers open; ash-pit doors cracked.	2	170	2	4	49	9.2	Average.
141	...do.....	.23- .24	.....	.....	.55	.....	Dampers open.....	1	30.	0	0	58	0	Heavy.
142	...do.....	.10- .12	.....	.....	.37	.50	.....do.....	[b]	[c]	0	0	60	0	Light.

[a] Combustion chamber.

[b] Several.

[c] Various lengths.

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Kind.	Draft. Readings (inches of water). Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.	Conditions under which readings were taken.	Smoke records. Number of observations.	Total length of observations (minutes).	Average for one hour (minutes). 100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.	Average percentage of black smoke from observations.	Load during observations.
143	Chimney..	0.12–0.14	.....	.....	.....	0.58	Ash-pit doors and dampers open.	2	60	0	0	.....	.....	Light.
144	...do.....	.12– .15	.....	.....	.....	.60–.65	Average conditions; dampers partly closed.	1	57	2	4	50	10	Heavy.
145	...do.....	.10– .15	.....	0.20–0.27	.....	.....	.....	1	60	0	1	53	3.7	Average.
146	...do.....	.08	.....	.16	.....	.47	.....	1	60	0	0	60	0	Do.
147	...do.....	.16– .18	[a] 0.36–0.40	.....	.....	.....	Ash-pit doors and damper open.	2	60	0	0	.....	.....	Light.
148	...do.....	.08– .16	.....	.....	.....	.....	Damper and dust-pit doors open.	2	60	0	2	55	1.7	Average.
149	...do.....	.10	.....	.....	.....	.40	Damper open; thin fire.....	(b)	(c)	0	0	.....	.....	Light.
150	...do.....	.12	[d] .20	.....	0.67–0.75	.90	Dampers partly closed.....	(b)	(c)	0	0	55	.....	Do.
151	...do.....	.10– .12	.25	.....	.30– .55	.....	Dampers open.....	(b)	(c)	0	0	.....	.....	Heavy.
152	...do.....	.....	.....	.....	.85	.....	.....do.....	(b)	(c)	0	0	.....	.....	Do.
153	...do.....	.10– .16	.....	.....	.32	.55	Dampers open; thin fire; ash-pit doors cracked.	1	30	0	3.5	44	12	Average.
154	...do.....	.17	.....	.32	.....	.56	.....	1	60	0	2	53	4.7	Do.
155	...do.....	.24– .29	.....	.....	.38– .40	.65	.....	1	60	0	0	60	0	Do.
156	...do.....	.17– .20	.....	.33	.....	.54	.....	1	60	0	1	57	2	Heavy.
157	...do.....	.18	.....	.....	.50	.....	Damper and ash-pit doors open.	1	110	2	2	53	6.2	Average.
158	...do.....	.35– .40	[d] .45	.....	.85– .95	.....	Dampers open.....	2	55	0	0	59	0	Do.
159	...do.....	.13– .15	.....	.....	.42– .45	.62	Thin fire; dampers partly closed.	2	65	0	0	55	3	Light.
160	...do.....	.10– .32	.....	.....	.....	.75	Dampers open.....	(b)	(c)	0	0	.....	.....	Do.
161	...do.....	.16– .19	.....	.30	.....	.55	.....	(b)	(c)	0	0	55	2	Heavy.
162	...do.....	.25– .27	.....	.....	.53	.....	Damper open.....	1	40	0	0	58	1	Average.
163	...do.....	.12– .15	.....	.....	.45	.....	Damper partly closed.....	1	57	0	1	.....	.....	Do.
164	...do.....	.27– .30	.....	.....	.47– .50	.47–.50	Dampers and ash-pit doors open.	(b)	(c)	0	0	.....	.....	Light.
165	...do.....	.22	.....	.43	.60	.76	Thin fire.....	1	300	0	0	56	1.7	Average.

[a] Upper rear. [b] Several. [c] Various lengths. [d] Combustion chamber.

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
120	16	6 x 5	Near stack	1	185	a 10	78.5	
121	15			1	230	6 x 6	36	
122	30	4 x 4	Near stack	1	160	4 x 4	16	Smokes considerably. 10 to 20 per cent black.
123	0			1	150	a 5.3	22.2	
124	47	4 x 3.5	Near stack	1	125	5 x 5	25	Shavings fed continuously through openings over the furnace doors. Automatic regulator on main damper. Stack smokes considerably, 10 to 40 per cent black.
125	48	3.5 x 4	45′ from stack	1	180	a 3.5	9.6	
126	0.15			1, 2	100, 90	a 3, 2.2x2.7	7.06, 5.8	Plant has damper regulator but it is not used: when it is in service there is difficulty in keeping smoke down. Trouble in carrying load and keeping down smoke when coal smaller than No. 3 is burned. Plant often runs with furnace door open.
127	15			1	90	3.7 x 3.7	13.4	
128	15			1	90			Smoke due to poking fire. Coal not equally distributed along grates.
129	9			1	120	a 5	19.6	Smokes continuously, 20 per cent black.
130	3			0	100	a 4.3	14.7	Smokes continuously, 30 per cent black.
131	11			0	100	a 4.3	14.76	
132	11			0	53	a 2.5	4.9	
133	28			1	85	4 x 4	16	Plant has automatic regulator on stack damper.
134	12			0	220	a 4.3	15.7	
135	18			1	220	a 6.5	33.2	Boilers arched over top for gas passage.
136	40			1	135	a 5	19.6	
137	20			1	140	3.5 x 3.5	12.3	Smokes continuously, 10 per cent black.
138	2			2	88	a 4.6	16.5	Boilers arched over top for gas passage.
139	7			0	138	a 6.5	33.2	
140	6			2	150	a 4.5	15.9	
141	8			1	100	a 5	19.6	Boilers arched over top for gas passage. Automatic regulator attached to main damper.
142	6			1	175			Boilers arched over top for gas passage.
143	0	0		0	100	a 6	28.3	Readings include some 10 and 20 per cent black smoke. Boilers arched over top for gas passage.
144	26			1	100	4 x 4	16	
145	15			1	90			Fires have to be poked frequently to keep grates covered.
146	50			3	120	a 3	7.06	
147	0	0		0	100	a 5	19.6	Stack rests on rear of boilers. Readings include some 10 and 20 per cent black smoke. Boilers arched over top for gas passage.
148	3			0	115	a 3	7.06	Boilers arched over top for gas passage. With ash-pit doors closed, draft in furnace varied from 0.17 to 0.32 inch water.

a Diameter.

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
149	5	.....	.....	0	100	3 x 3	9	Smoke observations include some 10 and 20 per cent black readings.
150	4	.....	.....	0	165	*a* 5	19.6	Boilers arched over top for gas passage. Very clean stack; observations include a few 10 per cent black readings.
151	17	.....	.....	3	158	4 x 5	20	None of the observations showed more than 20 per cent black smoke.
152	4	.....	.....	0	150	*a* 5	19.6	Observations include several 20 and 40 per cent black readings.
153	4	.....	.....	1	103	*a* 4	12.56	Coal does not work down grates properly and fire is poked vigorously every eight to fifteen minutes, causing two to three and one-half minutes of smoke each time.
154	28	.....	.....	1	100	2.7x 4	10.7	Stack generally good. Trouble sometimes with coal feed.
155	9	.....	.....	0	100	*a* 4	12.56	Observations have been taken that are not as good as record given. Automatic regulator attached to main damper.
156	23	.....	.....	2	110	2 x 3.4	6.7	
157	8	.....	.....	0	149	*a* 2.5	4.9	One side of each stoker flanked with fire brick.
158	6	.....	.....	0	160	*a* 6	28.3	Boilers arched over top for gas passage.
159	4	.....	.....	2	150	*a* 6	28.3	Do.
160	5	.....	.....	2	120	*a* 3.2	7.85	A ¼-inch steam jet entering the furnace through a 1-inch opening in door runs continuously. Observations include some 10 and 20 per cent black readings. Automatic regulator on main damper.
161	15	.....	.....	1	100	*a* 4	12.56	Boiler arched over top for gas passage.
162	6	.....	.....	0	90	.....	.....	
163	3	.....	.....	1	90	*a* 3.5	9.6	Usually a very good stack. Damper controlled by automatic regulator. Boilers arched over top for gas passage.
164	18	.....	.....	0	100	*a* 2.5	4.9	Stack smokes occasionally, 10, 20, and 40 per cent black.
165	0	.....	.....	0	100	4 x 4	16	Boilers arched over top for gas passage.

a Diameter.

SUMMARY.

The importance of installing the side-feed stoker with an arch over the entire grate can not be too strongly urged. At nearly every plant observed where this stoker had been installed with a short ignition arch only, trouble was experienced in keeping down smoke.

Some of the stacks having this stoker under them smoked badly because the fireman took advantage of the opening into the furnace and fired a part of the coal by hand.

There was some trouble in maintaining a uniform feed of coal at a few of the plants visited. This seemed to happen when very fine coal was supplied. With this stoker as ordinarily set, a banked fire can be maintained and the boiler thrown into service with only a small amount of smoke. The stoker has the valuable feature of a large coking plate area.

UNDERFEED STOKERS.

GENERAL DISCUSSION.

Stokers of the underfeed type differ radically from those described in the preceding pages. The fresh coal is forced into a horizontal retort, beneath that which has already ignited, and burns in a long heap that forms in the middle of the furnace. The unburned refuse is largely fused to a clinker, which slides down the sides of the heap and is hooked out by hand through the front of the furnace. The method of burning compels the use of mechanical draft, a fan being employed to force air through openings in tuyère blocks along the sides of the retort, at the level where the volatile hydrocarbons from the heap of burning coal are given off. Two makes of this stoker that have been put to the test of use under average power-plant conditions differ chiefly in the feeding mechanism and the device for handling the partly burned coal after it leaves the retort. In one pattern the coal is forced in continuously by a cone-shaped screw driven by a small steam engine, and the partly burned coal falls on a flat grate through which air is drawn by a chimney. In the other pattern the coal is pushed beneath the burning heap in large charges, and the partly burned coal that rolls down the sides of the heap falls on a dead plate, where combustion is completed by the excess air that enters through tuyère openings. This method of burning coal has proved to be the better, and the plan of using air from the tuyères for complete combustion has been generally adopted as correct. The newer models of underfeed stokers are always installed with automatic control for coal and air.

In all underfeed stokers the air and the distilled gases are intimately mixed and intensely heated by rising through the incandescent coal, so that combustion is complete within a very short distance from the

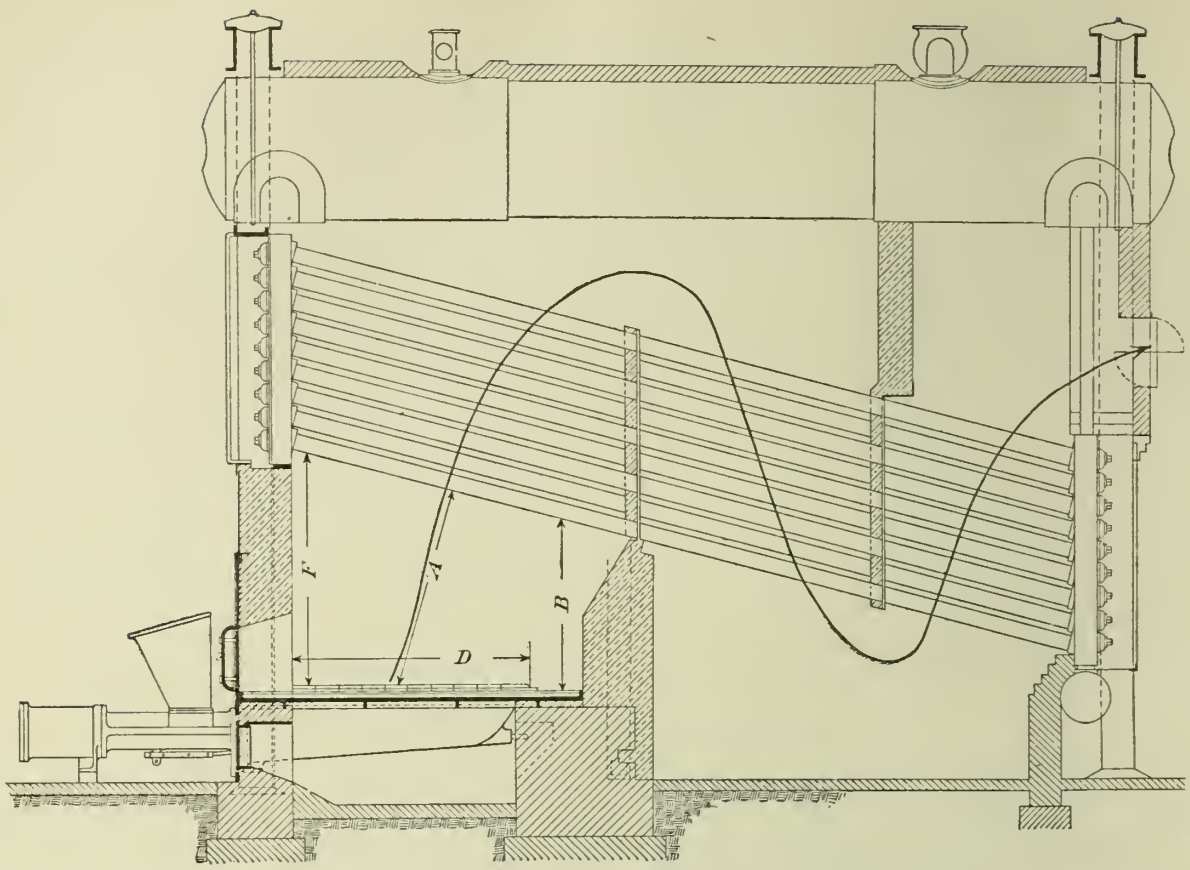


FIGURE 17.—Underfeed stoker and Babcock & Wilcox boiler.

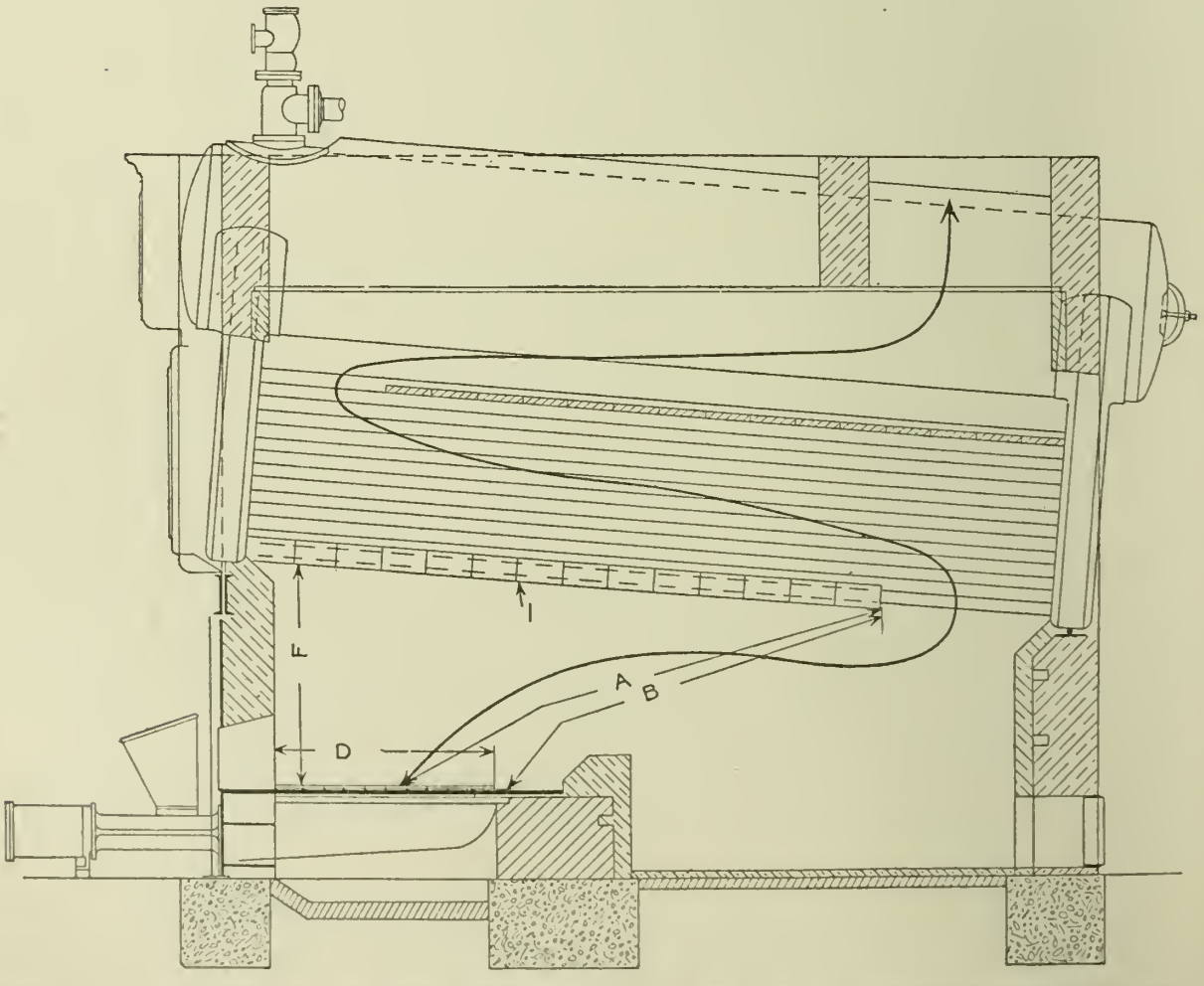


FIGURE 18.—Underfeed stoker and Heine boiler. 1, C tile on lower row of tubes, forming a tile-roof furnace.

retort. Hence the combustion space required over the fuel bed is less than with any other type. By reason of its compactness and the small combustion space it demands, the underfeed stoker sometimes gives good results when installed in the 36-inch corrugated flue of an internally fired boiler.

The customary method of placing this stoker under a Babcock & Wilcox boiler with uptake in the rear is shown by figure 17. In the setting of the Heine boiler (fig. 18) the C tile on the lower stow of water tubes make a tile roof for the furnace. This increases the travel of the gases from the fire and permits complete combustion of the

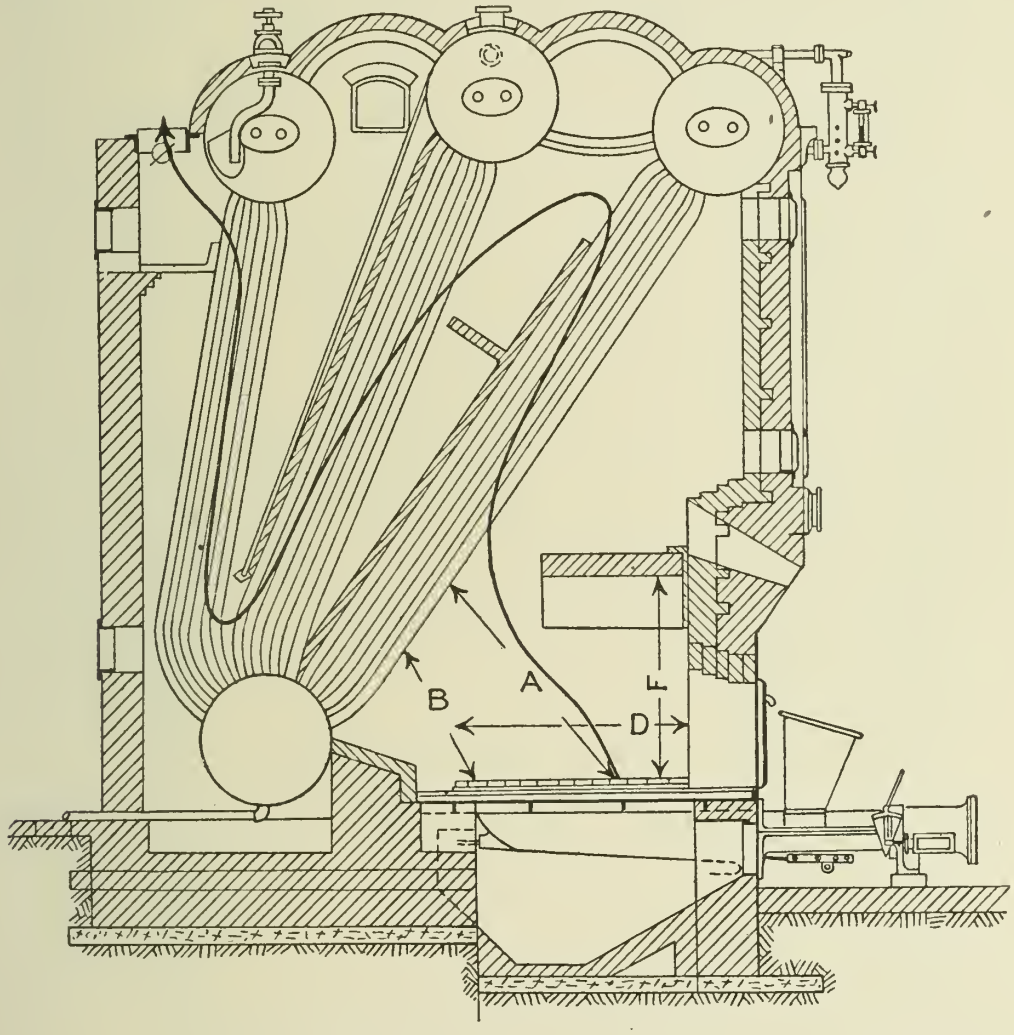


FIGURE 19.—Underfeed stoker and Stirling boiler.

carbon before the gases are chilled by contact with the tubes. In the regular setting of the Stirling boiler (fig. 19) the stoker is placed under the fire-brick arch. The construction of one of the makes of underfeed stokers is shown by figure 20, an elevation of a stoker under a return tubular boiler; figure 21, a cross section through boiler and stoker; figure 22, a plan of the stoker.

Attention has been called to the compactness of the underfeed stoker and the small amount of space required above the grate. An illustration showing such a stoker set in the corrugated flue of a Scotch boiler is given in figure 23.

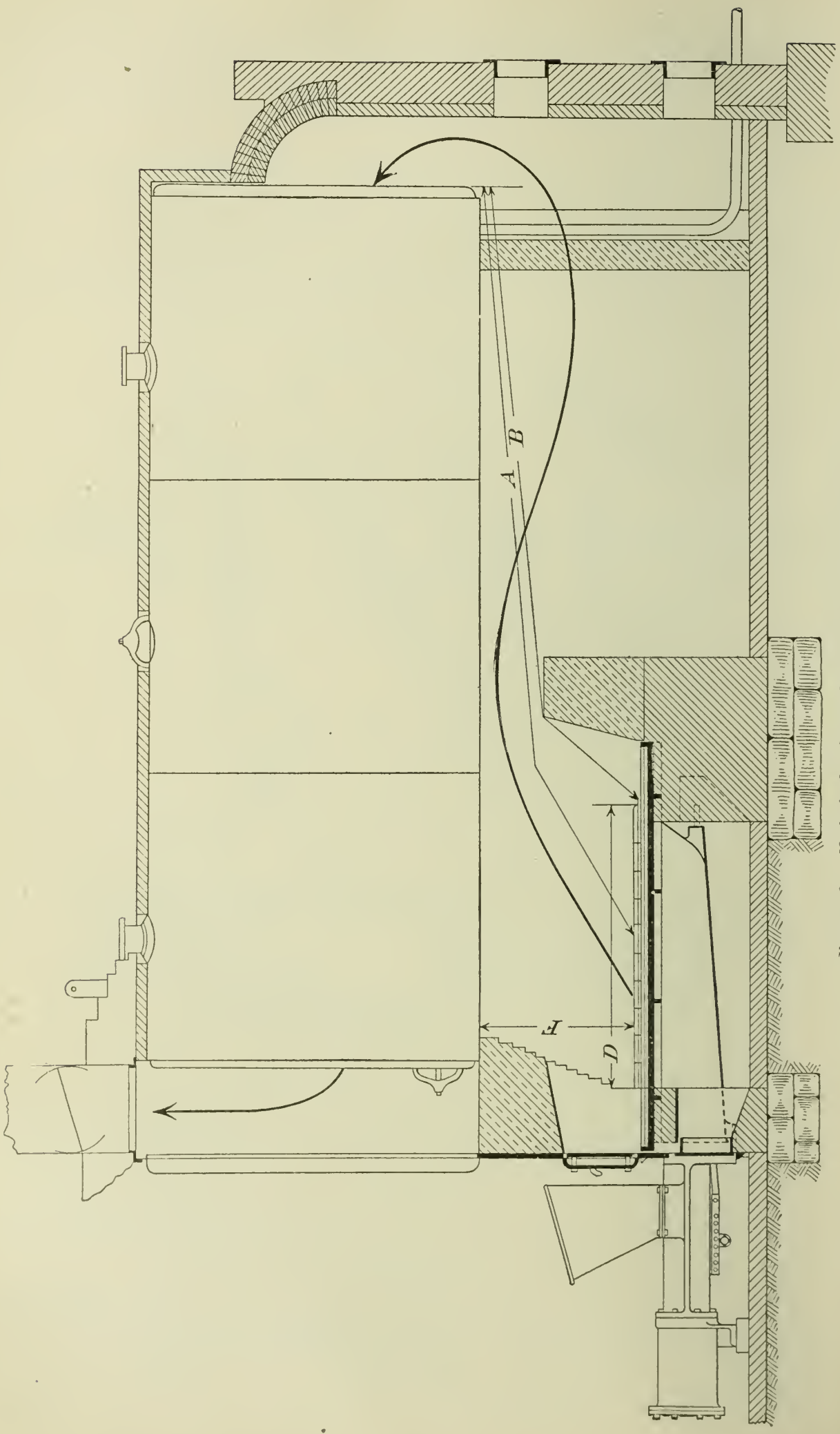


FIGURE 20.—Underfeed stoker and return tubular boiler, elevation

Having the advantage of positive draft, the underfeed stoker allows a plant to be run without regard to weather conditions that may make the attainment of high draft by a stack impossible. The effects of weather changes on furnace draft are considerable and are very noticeable at plants which require all the available draft to carry their loads. Another valuable feature of this stoker is the ease and economy with which a variable load may be carried. The change from heavy to

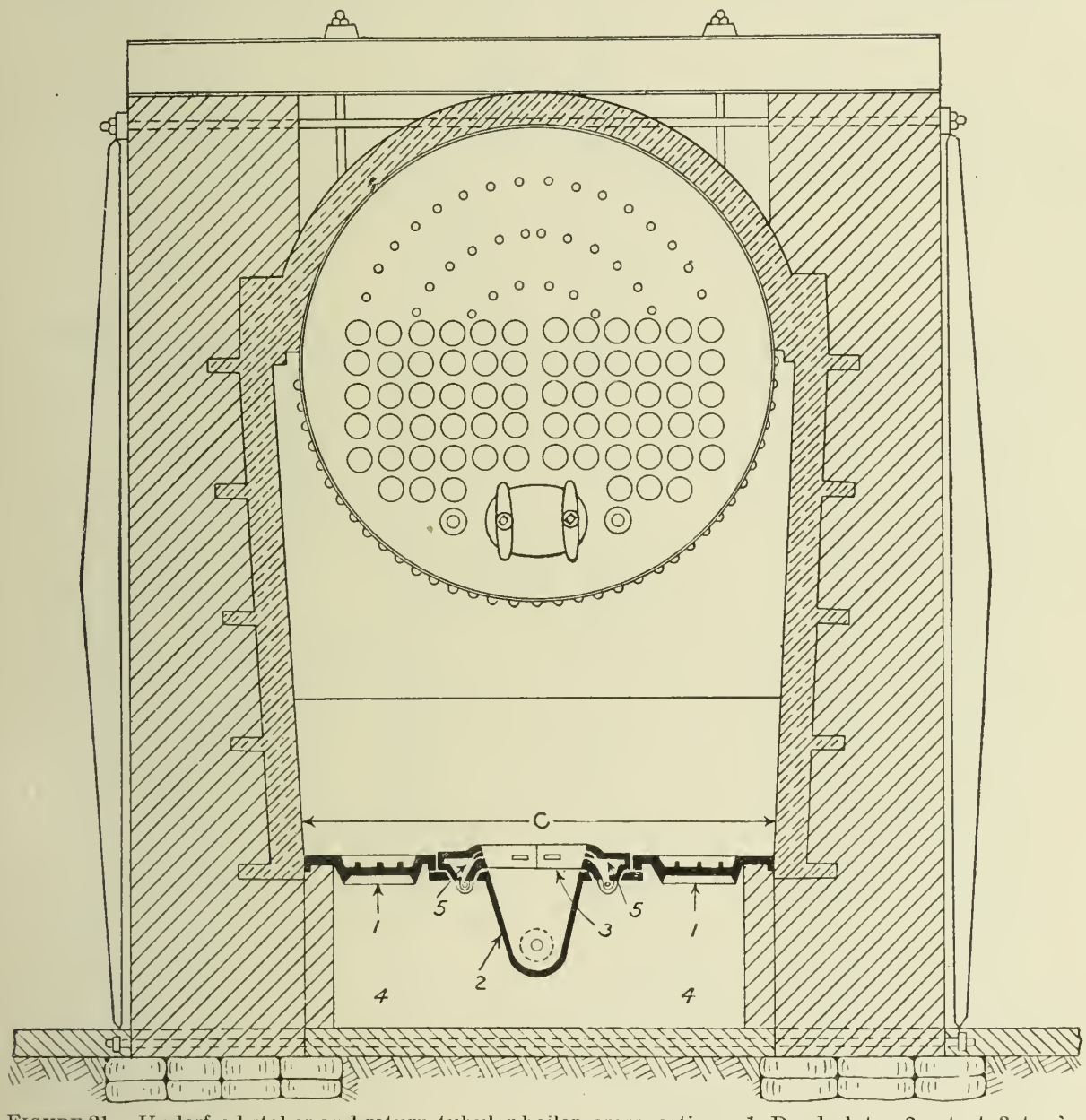


FIGURE 21.—Underfeed stoker and return tubular boiler, cross section. 1, Dead plates; 2, retort; 3, tuyère blocks; 4, air chamber; 5, space through which air passes before entering retort.

light coal charges or vice versa can be made without loss, because when the fuel supply is altered the air supply is at once regulated to the amount of coal being burned.

It sometimes happens that, to meet the competition of other types, a single underfeed stoker is installed under a boiler unit as large as 200 horsepower. It is easy to show that such overloading of a stoker is not good business economy, particularly in localities where poor coal is supplied. On the assumption of an average ratio of heating

surface to grate surface of 50 to 1, a 200-horsepower boiler should have 40 square feet of grate. Now while it is possible to burn, say 30 pounds of average coal per square foot of grate surface per hour, or 1,200 pounds of coal per hour for a 200-horsepower boiler, it is not

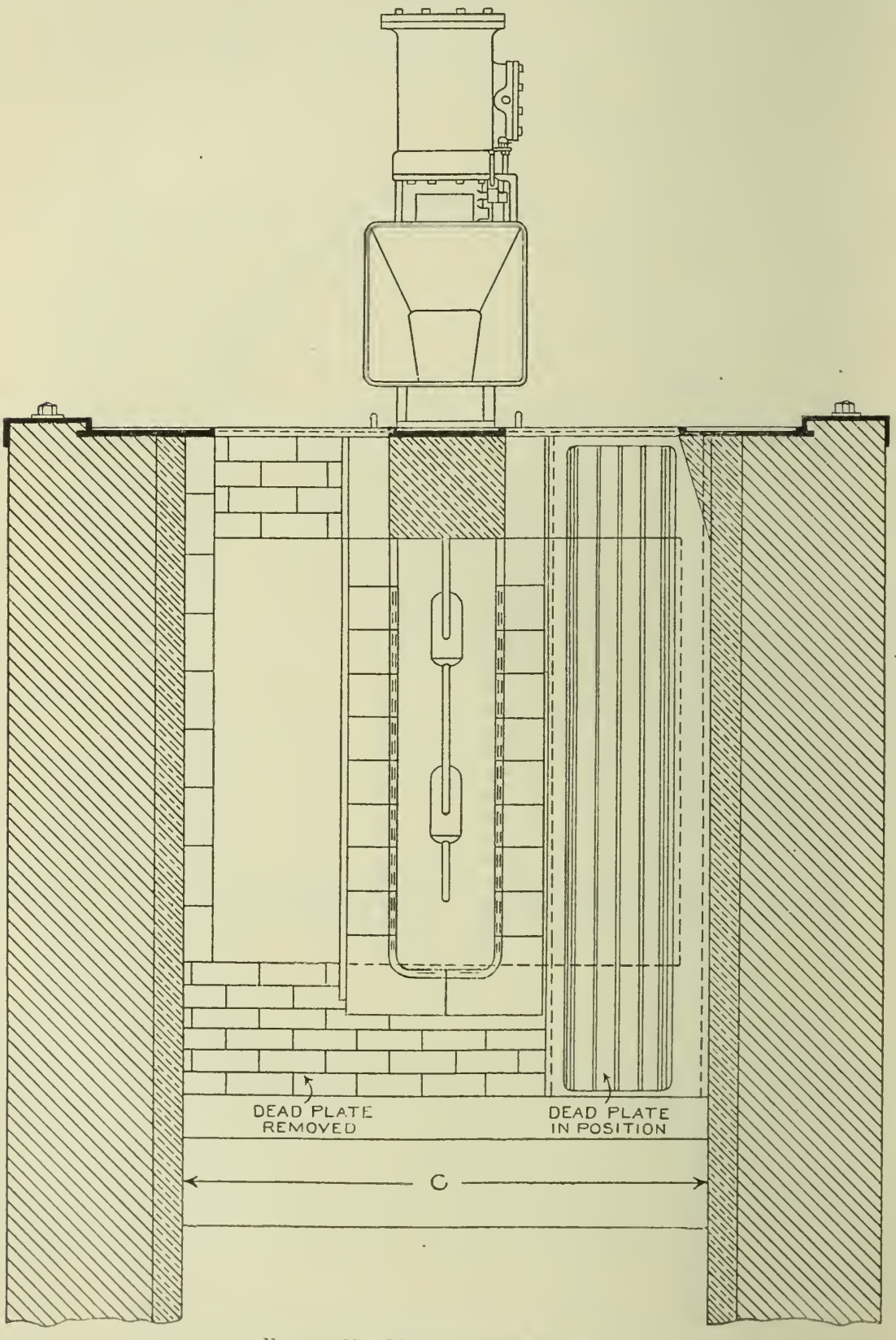


FIGURE 22.—Plan of underfeed stoker.

considered good practice to try to burn over 700 to 800 pounds of coal per stoker per hour with an underfeed stoker, as heavier feeding gives questionable results. The consequence of trying to feed 1,200 pounds of dirty coal per hour with one stoker of this type is evident.

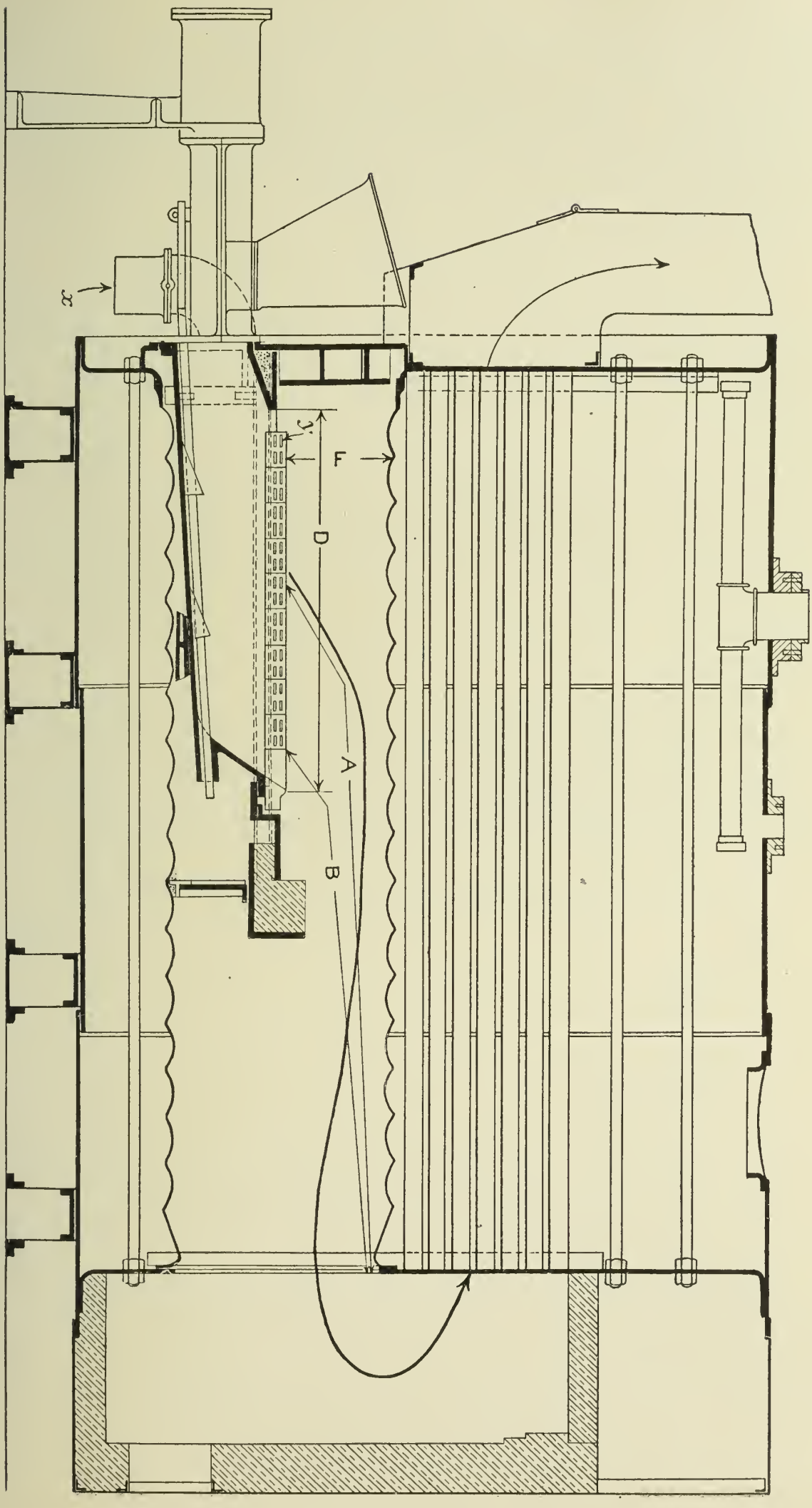


FIGURE 23.—Underfeed stoker and Scotch marine boiler. *x*, Pipe through which air is admitted under retort; *y*, air-admission openings in tuyère blocks.

It is the general opinion that it is harder to keep down smoke at the small hand-fired return tubular boiler plant than anywhere else, but the underfeed stoker has replaced many hand-fired furnaces at such plants. The only variable element in the operation of this stoker, once it is correctly installed, is the cleaning of fires, but if the fireman is careful to burn down the fires before breaking them up there will be no necessity of making smoke.

DETAILED DESCRIPTION OF PLANTS.

The underfeed type of stoker was found at 48 different plants in eight different States, the size of the plants ranging from 75 to 3,500 rated boiler horsepower. These plants burned coal from Illinois, Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia, the cost of which ranged from $1.03 to $2.75 per ton, the conditions at the different plants varying widely. The size of the boiler units ranged from 50 to 500 horsepower; at 33 plants the units were 200 horsepower or less, and with two exceptions one stoker per boiler was installed at these plants. All but five of the plants had automatic regulators for coal or air. But two of these stokers were set in a Dutch oven; this setting was used because the boilers were of the vertical type.

Plants with water-tube boilers.—Underfeed stokers were found under water-tube boilers at 22 plants, at 4 of which the fuel was run-of-mine coal. At 13 plants the load carried was uniform, and at 9 it was variable. The thickness of fire ranged from 8 to 18 inches. The kind of coal burned is stated in the following summary:

Kind of coal burned at plants with underfeed stokers under water-tube boilers.

	Number of plants.[a]
Illinois	5
Indiana	1
Kentucky	1
Ohio	7
Pennsylvania	8
West Virginia	1

Some averages of the observations at these plants are given below:

Difference of draft between ash pit and furnace, 3 inches of water.

Coal as received burned per stoker per hour, average heavy load, 560 pounds; extremes, 330 and 1,060 pounds.

Percentage of rated boiler horsepower developed average heavy load (boiler rated on 10 square feet of heating surface per horsepower), 92; extremes, 58 and 146.

Average distance from grate to heating surface (dead plates to shell), 4.9 feet; extremes, 3 and 7.5 feet.

[a] One plant burned both Ohio and Pennsylvania coal.

Least distance from grate to heating surface (dead plates to shell), 3.8 feet; extremes, 2 and 5.3 feet.

Smoke, black, 2.4 per cent.

Average draft conditions: Pressure in ash pit, 17 plants, 2.45 inches of water; range, 1 to 4 inches. Draft in furnace, 19 plants, 0.33 inch; range, 0.01 to 1 inch. Draft in rear of boiler, 13 plants, 0.48 inch; range, 0.17 to 1.07 inches. Draft at base of stack, 11 plants, 0.80 inch; range, 0.24 to 1.50 inches. The approximate pressure and drafts deduced from these readings are as follows: Pressure in ash pit, 2.50 inches of water; draft in furnace, 0.35 inch; draft at rear of boiler, 0.50 inch; draft at base of stack, 0.80 inch. This gives a drop of about 3 inches through the fuel bed, of about 0.15 inch through the boiler, and of 0.30 inch from the boiler to the stack.

Details of the observations at plants with underfeed stokers under water-tube boilers are given in Table 16.

TABLE 16.—*Details of observations at plants with underfeed stokers under water-tube boilers.*

No of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
166	Missouri	Jones	3,500	Various coals	Illinois	Various sizes	$1.03	
167	do	do	2,000	do	do	do	1.03	
168	do	do	2,000	do	do	do	1.03	
169	Illinois	do	1,875	Screenings	do	1 to 1½ inches		
170	do	do	400	Washed nut	Marion County, Ill	No. 1 nut		
171	Indiana	do	230		Indiana	Nut and slack		
172	do	American	728	Straight Creek	Kentucky	do		
173	Ohio	Jones	909	Coshocton	Ohio	Slack	2.00	6,000
174	do	do	600	Hocking Valley	do	1-inch screenings	1.80	
175	Michigan	do	300	Cambridge	do	Slack	1.65–1.70	
176	do	do	300	do	do	do	1.65–1.75	
177	Ohio	do	200	Pittsburg No. 8	do	1-inch nut	2.40	1,400
178	do	do	200	Hocking Valley	do	Pea and slack	1.80	4,800
179	Pennsylvania	do	1,400	Clearfield	Pennsylvania	Run of mine		
180	Ohio	do	800	Pittsburg nut and slack	do	Through 1½-inch screen	1.80	
181	Pennsylvania	do	720	Pittsburg second pool	do	Slack	1.30	5,200
182	Ohio	American	700	Various coals	Ohio and Pennsylvania	¾-inch screenings	1.50–1.65	
183	Pennsylvania	Jones	600	Nanty Glo	Pennsylvania	Run of mine	3.05	
184	New York	do	320	Youghiogheny	do	Slack and run of mine	2.35–2.50	6,900
185	do	do	300	Rochester and Pittsburg; Reynoldsville.	do	Slack	2.35	1,500
186	Pennsylvania	do	276	Pittsburg	do	Run of mine	2.75	
187	Michigan	do	275	Thacker	West Virginia	Slack	2.50	1,500

TABLE 16.—*Details of observations at plants with underfeed stokers under water-tube boilers*—Continued.

No. of plant.	Load.			Rating.							
				Average load.							
				Heavy.		Light.		Coal burned per stoker per hour, average heavy load (pounds).	Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
	Requirement.	Nature.	Character.	Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).				
166	Power	Variable	Street railway	20	111	20	111	528	76	64	5
167	do	do	do	20	64	20	64	533	76	64	5
168	do	do	do	20	64	20	64	533	76	64	5
169	Power and light	do	Office building	8	22	8	18	450	79	80	5
170	do	Uniform	Refrigeration	24	10	24	12	420	81	83	5
171	Power, light, and heat	Variable	Bakery			24	5	416	83	72	5
172	do	Uniform	Factory	9.5	10	9.5	13	1,000	130	130	5
173	do	do	Store building	10	12	10	15	600	92	79	5
174	do	do	do	10	8	10	8	400	59	59	4.5
175	do	do	Factory	10	4.5	10	3.3	450	59	60	5
176	do	do	do	10	4.5	10	3.3	450	59	60	5
177	Light and heat	do	Office buildings	24	6	12	1.3	250	78	63	4
178	do	Variable	Commercial	24	12	24	9	500	91	100	5
179	Power and heat	Uniform	do	24	60	24	20	625	112	90	4
180	Power, light, and heat	Variable	Factory	10	10.4			1,040	115	115	4.5
181	do	do	Office building	16	10			625	58	58	4
182	do	Uniform	Factory	12	17	12	17	710	95	81	5
183	Power and heat	Variable	do	9	15	9	8	830	139	139	4
184	Power, light, and heat	Uniform	Hotel	24	19	24	19	527	146	165	4
185	do	do	Organization building	24	7.9	16	4	330	68	60	3.6
186	Power	do	Factory	10	7	10	7	700	146	127	4
187	Power and heat	do	Office building	10	3.5	10	3.5	350	78	78	4.5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 16.—*Details of observations at plants with underfeed stokers under water-tube boilers*—Continued.

No. of plant.	Stoking.			Boilers.									
	Method.	Thickness of fire (inches).	Frequency of cleaning fire.	Type.	Size.	Number installed.	Number used to carry—		Builder's rated horsepower.	Horsepower, boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
							Average heavy load.	Average light load.					
166	Automatic	14	5 times in 20 hours.	O'Brien	228 3½″ x 18′ tubes	7	7	7	500	418	4,180	0	160
167	do	14	do	do	do	4	4	4	500	418	4,180	0	160
168	do	14	do	do	do	4	4	4	500	418	4,180	0	160
169	do	Variable.	3 times in 24 hours.	Stirling	286 3¼″ tubes, 3 36″ x 14′ drums	5	4	3	375	378	3,780	0	150
170	do		6 times in 24 hours.	Scotch marine	142 4″ x 12′, 10′ shell	2	1	2	200	205	2,050	0	140–145
171	do		4 times in 24 hours.	Babcock & Wilcox.	54 4″ x 16′ tubes, 1 36″ drum	2		1	115	100	1,000	0	80–90
172	do		Once in 9 hours	Stirling	Two, 176 3½″ tubes; one, 280 3½″ tubes—3 36″ drums each.	3	2	1, 2	200, 328	200, 328	2,000, 3,280	0	115
173	do		4 times in 24 hours.	do		3	2	3	303	262	2,618	1,345	150
174	do	Variable.	Once every 4 hours	Park		2	2	2	300	304	3,035		100–120
175	do	12–15	2 times in 10 hours.	Wickes vertical.		1	1	1	300	307	3,065	0	150
176	do	12–15	do	do		1	1	1	300	307	3,065	0	150
177	do			Scotch marine	56 3½″ x 12½′ tubes	2	2	1	100	80	800	0	100
178	do	12–15	2 times in 8 hours	McNaull	128 4″ x 15′ tubes	1	1	1	200	220	2,200	0	95–120
179	do		2 to 3 times in 24 hours.	Edgemoor	131 4″ x 18′ tubes, 3 35″ x 20′ drums.	4	4	3	350	280	2,800	0	85
180	do	Variable.	2 times in 10 hours.	Atlas	140 4″ x 18′ tubes between water legs.	2	1	1	400	401	4,013	(a)	120
181	do	15–18	Once in 8 hours	Gill	96 4″ x 16′ tubes	4	3		180	180	1,800	0	120
182	do			Stirling		2	2	2	350	300	3,000	0	110
183	do		3 times in 9 hours.	Babcock & Wilcox.	144 4″ x 18′ tubes, 1 42″ drum.	2	2	2	300	300	3,000	0	125
184	do	15	3 to 6 times in 24 hours.	do	48 4″ x 16′ tubes	4	3	3	80	90	900	0	90
185	do	8–15	3 to 4 times in 24 hours.	National	72 4″ x 16′ tubes	2	2		150	135	1,345	0	100
186	do		2 times in 10 hours.	Babcock & Wilcox.	64 4″ x 16′ tubes, 1 36″ drum	2	2	2	138	120	1,200	0	110
187	Hand-operated.	12–15	1 to 2 times in 10 hours.	Wood horizontal.		3	2	2	100, 75	2–100 1– 75	1,000, 750	0	125

a 10° to 24° F. superheat.

TABLE 16.—*Details of observations at plants with underfeed stokers under water-tube boilers*—Continued.

No. of plant.	Furnaces.							
	Kind.	Number of stokers per boiler.	Dimensions (feet).					
			Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance at front of furnace from grates to coking arch or heating surface (F).
			Average (A).	Minimum (B).				
166	Plain	3	4.5	4	11	6.3	0	5
167	do	3	4.5	4	11	6.3	0	5
168	do	3	4.5	4	11	6.3	0	5
169	do	3	7.5	5.3	12.2	6.3	0	4.5
170	Corrugated flue	2	10	7	3	7.5	0	1.4
171	Plain	1	4.5	3.8	3.8	6.3	0	5
172	do	(a)					0	3.2
173	do	2	7.5	4.5	8.5	6.3	0	4
174	do	2	5	4	8.75	6.3	0	5
175	Dutch oven	2	6	3	8	6.3	9	5.25
176	do	2	6	3	8	6.3	9	5.25
177	Corrugated flue	1	11	8	3.2	6.3	0	1.5
178	Plain	2	4.3	4	8.5	6.3	0	4.3
179	do	2	4.75	4.5	9.5	6.3	0	5
180	do	2	4.8	4.8	8.8	6.3	0	5
181	do	1	3.5	3		6.3	0	3.5
182	do	2	7	4		6.3	0	4.5
183	do	2	4	3.5	9.7	6.3	0	4.8
184	do	1	3.5	3	4	6.3	0	4
185	do	1	3.5	3	5	6.3	0	3.5
186	do	1	4	3.5	5	6.3	0	4.5
187	do	1	3	2	4	6.3	0	2.5

a Two on 328 horsepower; one on 200 horsepower.

TABLE 16.—*Details of observations at plants with underfeed stokers under water-tube boilers*—Continued.

No. of plant.	Kind.	Draft and pressure. Readings (inches of water). Pressure in ash pit.	Draft. Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.	Conditions under which readings were taken.	Smoke records. Number of observations.	Total length of observations (minutes).	Average for one hour (minutes). 100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.	Average percentage of black smoke from observations.	Load during observations.
166	Chimney and forced.	3.6	0.28	0.48	.....	.....	.....	.....	1	60	0	0	56	1.3	Average.
167	.....do.....	2.8	.33	.53	.....	.....	.....	.....	1	60	0	0	56	1.3	Do.
168	.....do.....	3	.34	.54	.....	.....	.....	.....	1	60	0	0	56	1.3	Do.
169	.....do.....	.....	0.86–1.02	[a].98–1.16	.....	.....	1.50	Dampers open, fan running at maximum speed.	9	501	0	0	40	10.3	Do.
170	Induced and forced..	0.90–1.13	.35	.....	0.70	.....	.....	.....	1	60	0	0	57	1.1	Light.
171	Chimney and forced.	2.25	.32	.39	.....	.....	.....	Average conditions; damper partly closed.	2	80	0	0	[c]	4.8	Do.
172	.....do.....	.....	.32–.35	[a].40–.42	.....	0.61	.....	Average conditions; ash pit doors cracked.	1	50	2	0	53	5.8	Do.
173	.....do.....	2	.20–.30	[b].33–.40	.....	.50	.....	.....	1	600	0	0	60	0	Average.
174	.....do.....	1	.48	.....	.....	0.52–.56	.57	Average running conditions.	1	60	0	0	60	0	Do.
175	.....do.....	2	.20	[a].28	.....	.....	.70	.....	1	60	0	0	59	.3	Do.
176	.....do.....	2	.23	[a].50	.....	.....	.64	.....	1	60	0	0	60	.3	Heavy.
177	.....do.....	.25	.17–.25	.....	.70	.....	.88	.....	1	600	0	0	60	0	Average.
178	.....do.....	4	.32	.....	.....	.90	1	Damper open.	1	60	0	.5	58	1.9	Do.
179	.....do.....	2.1	.25–.55	.55–.78	.....	.....	.....	Dampers wide open.	1	40	0	0	48	5	Heavy.
180	.....do.....	2.3	.....	.....	.....	.80	.....	Damper open; fan running at average speed.	[d]	.....	0	0	.....	.....	Do.
181	.....do.....	2–3	.43–.66	.....	.....	.....	.....	.....	1	60	0	0	60	0	Light.
182	.....do.....	1.5	.44	[a].60	.....	.....	.92	.....	1	60	0	2	49	6.7	Average.
183	.....do.....	3–3.2	.10–.17	.34–.44	.....	.....	.9–1	Damper one-half open; furnace doors cracked 3 inches.	1	90	0	0	60	0	Light.
184	.....do.....	2	.28–.50	.....	.....	.....	1	.....	1	120	0	0	50	3.2	Average.
185	.....do.....	2	.12	.19	.....	.....	.24	.....	1	60	0	0	59	.4	Heavy.
186	.....do.....	3.5	.15	.....	.....	.....	.40	.....	2	58	10	.5	55	4.3	Average.
187	.....do.....	.....	0–.02	.14–.19	.....	.....	.90	.....	1	60	0	1	55	3.1	Do.

[a] Lower rear boiler. [b] Upper rear boiler. [c] See remarks. [d] Several.

TABLE 16.—*Details of observations at plants with underfeed stokers under water-tube boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
166	0	.....	.....	0	80	[a] 4.5	15.9	Seven stacks, each on rear of boiler.
167	8	4 x 4	Near stack.....	0	158	[a] 6.4	32.3	
168	0	.....	.....	0	80	[a] 6	28.3	Two stacks, each on rear of boiler.
169	32	[b] 70	50 feet from stack..	2	330	[a] 8	50.25	Coal varies from 11,000 to 12,000 B. t. u. per pound of dry coal; coal as received contains 10 to 12 per cent moisture, 11 to 17 per cent ash.
170	28	.....	.....	1	37	[a] 4	12.56	
171	4	.....	.....	1	85	3.3 x 3.3	11.1	With damper partly closed, as soon as fires begin to get dirty 20 to 30 per cent black smoke produced for about twenty seconds every time coal is fed. One observation taken while cleaning fire. Some smoke when coal is wet and usually while cleaning fire.
172	30	.....	.....	1	123	[a] 6.2	29.86	
173	80	.....	.....	2	165	[a] 5	19.6	Coal as fired runs about 12,800 B. t. u.; ash, 12 per cent; moisture, 3.5 per cent.
174	0	.....	.....	0	120	6 x 6	36	Stack on rear of boiler.
175	8	.....	.....	2	80	4 x 4	16	Stack smokes about 20 per cent black for about one minute when cleaning fires.
176	3	.....	.....	0	80	[a] 3.8	11.6	Do.
177	8	.....	.....	2	200	2.5 x 2.5	6.3	
178	15	.....	.....	1	162	[a] 6	28.3	Boiler baffled vertically.
179	23	.....	.....	8	150	6 x 6	36	Boilers baffled vertically, four passes. Four separate flues join main breeching. Stack smokes 10 to 40 per cent black for about half a minute every two or three minutes.
180	24	.....	.....	1	135	[a] 6	28.3	Observations include some 10 and 20 per cent black readings.
181	28	.....	.....	1	200	[a] 5	19 6	
182	10	.....	.....	0	125	[a] 6	28.3	Coal as received runs about 12,700 B. t. u. and 10 to 14 per cent ash.
183	0	.....	.....	0	120	[a] 4	12.56	Coal runs about 8 per cent ash. Stack rests on rear of boilers. Get best results when running at about rated capacity.
184	25	.....	.....	1	145	[a] 5	19.6	Boiler baffled vertically with top half of first baffle removed.
185	105	.....	.....	2	150	[a] 3	7.06	Coal as received runs about 13,600 B. t. u. and 10 per cent ash.
186	3	.....	.....	2	58	[a] 3	7.06	Cleaned fire during part of observations. Plant has burned 1,000 pounds of coal per stoker per hour, but made considerable smoke.
187	65	.....	.....	4	175	[a] 6	28.3	

[a] Diameter.

[b] Square feet.

Plants with return tubular boilers.—Underfeed stokers were installed under return tubular boilers at 26 plants. The fires carried ranged in thickness from 12 to 18 inches. Four of the plants burned run-of-mine coal. Seventeen carried a uniform load, and 9 a variable load. The kinds of coal burned were as follows:

Kind of coal burned at plants with underfeed stokers under return tubular boilers.

	Number of plants.[a]
Illinois	1
Indiana	4
Kentucky	1
Ohio	3
Pennsylvania	8
West Virginia	4
Miscellaneous	7

Various particulars regarding these plants are condensed in the following statement:

Coal as received burned per stoker per hour, average heavy load, 513 pounds; range, 225 to 750 pounds.

Percentage of rated boiler horsepower developed, average heavy load (boiler rated on 10 square feet of heating surface per horsepower), 74; range, 57 to 135.

Average distance from grates to shell, 2.8 feet; range, 2 to 3.75 feet.

Smoke, black, 2.6 per cent.

Approximate average pressure in ash pit, 1.75 inches.

Approximate average draft in furnace, 0.20 inch; at front tube sheets, 0.30 inch; at base of stack, 0.50 inch. This gives an average drop of 2 inches between the ash pit and the furnace, 0.10 inch through the boiler, and 0.20 inch from the boiler to the stack.

Details of the observations at plants with underfeed stokers under return tubular boilers are given in Table 17.

[a] Two plants burned both Ohio and West Virginia coal.

TABLE 17.—*Details of observations at plants with underfeed stokers under return tubular boilers.*

No. of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
188	Illinois	Jones	200	Washed	Williamson County, Ill.	No. 4		
189	do	do	3,500		Indiana	Screenings		
190	Indiana	do	700	Various coals	do	Run of mine, nut, and slack	$1.30–$1.60	
191	do	do	165		do	Nut and slack		
192	do	do	125		do	do		
193	Kentucky	American	100		Western Kentucky	Pea and slack		
194	Ohio	Jones	530	Goshen	Ohio	Slack	1.90	5,030
195	Michigan	do	300	Various coals	Ohio; West Virginia	Slack and run of mine	2.00– 2.15	
196	Ohio	do	200	Kanawha	West Virginia	Run of mine	2.30	2,600
197	Michigan	do	200	Various coals	Ohio; West Virginia	Pea and slack	2.05	1,300
198	Indiana	do	150		West Virginia	Slack		
199	New York	do	1,104	Shawmut	Pennsylvania	do	2.00	
200	do	do	860		do	Screenings		7,000
201	do	do	800	Rochester; Pittsburg	do		2.45	
202	do	do	736	Shawmut	do	Slack	2.00	
203	Ohio	do	625	Youghiogheny	do	do	1.70	7,500
204	New York	do	500	Shawmut	do	do	2.00	
205	do	do	260	do	do	do	1.95	2,880
206	Kentucky	American	150		do	Nut and slack		
207	Ohio	Jones	575	Various coals		Slack	1.85	
208	do	do	500	do		1-inch screenings	1.51	
209	do	do	500	do		Nut and slack	1.51	
210	do	do	375	do		1-inch screenings	1.51	
211	do	do	300	do		Pea and slack	1.70	2,000
212	Pennsylvania	do	250			Run of mine	3.00	
213	Illinois	do	75	Various coals				

TABLE 17.—*Details of observations at plants with underfeed stokers under return tubular boilers*—Continued.

No. of plant.	Load.			Rating.							
				Average load.							
				Heavy.		Light.		Coal burned per stoker per hour, average heavy load (pounds).	Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horse power per hour (pounds).
	Requirement.	Nature.	Character.	Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).				
188	Power and heat	Variable	Factory	8	4.5	8	4	560	135	112	5
189	Light and heat	do	School buildings	17	54	17	13.5	582	57	73	5
190	Power, light, and heat	Uniform	Factory	10	15	10	15	500	79	100	5
191	do	Variable	Store building	11	3.5	11	3.5	320	70	77	5
192	do	Uniform	Laundry	11	4	11	3.3	728	88	116	5
193	do	Variable	Organization building	18	4	18	2.8	225	70	89	5
194	do	Uniform	Brewery	24	15.4	24	12.6	427	50	68	5
195	do	do	Factory	10	5	10	5	500	58	74	4.5
196	do	Variable	Glass works	12	9	.....	.....	750	100	167	4.5
197	do	Uniform	Printing office	10	3.6	10	2.3	360	58	72	5
198	do	do	Factory	14	3.5	14	3.5	500	104	148	4.5
199	Heat	Variable	Oil refinery	24	51	24	51	706	69	96	4
200	Power, light, and heat	Uniform	.....	24	24	24	18	500	55	58	4
201	do	do	Office building	14	13	14	4	620	66	79	4
202	Power and heat	Variable	Oil refinery	24	35	24	35	730	70	100	4
203	Power, light, and heat	Uniform	Salt works	12	13.6	12	11.4	565	70	100	4.5
204	Power and light	do	Oil refinery	10	11.7	10	11.7	585	102	117	4
205	Power	do	Refrigeration	12	4	24	10	330	.....	92	4
206	Power, light, and heat	Variable	Hospital	24	4	24	2.4	335	63	89	5
207	do	Uniform	Refrigeration	24	22.3	24	17.8	620	76	88	5
208	Heat	do	Commercial	24	26	.....	.....	545	80	87	5
209	do	do	do	24	20	.....	.....	416	61	67	5
210	do	do	do	24	19	.....	.....	535	80	87	5
211	Power, light, and heat	do	Laundry	12	5.5	12	5.5	460	65	68	4.5
212	Power	do	Refrigeration	24	14.5	24	13.4	600	104	121	4
213	Power and heat	Variable	Machine shop	9	1.5	9	1.25	340	68	91	5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 17.—*Details of observations at plants with underfeed stokers under return tubular boilers*—Continued.

No. of plant.	Stoking.			Boilers.								
	Method.	Thickness of fire (inches).	Frequency of cleaning fire.	Size.	Number installed.	Number used to carry—		Builder's rated horsepower.	Horsepower, boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure. at gage.
						Average heavy load.	Average light load.					
188	Automatic		1 to 2 times in 8 hours	60″ x 16′, 42 41″ tubes	2	2	2	100	83	830	0	110
189	do		Once in 8 hours	72″ x 18′, 135 3″ tubes	20	10	3	175	223	2,225	0	
190	do		4 times in 10 hours	66″ x 16′, 64 4″ tubes	7	6	6	100	126	1,260	0	90
191	do		2 times in 11 hours	1 60″ x 14′, 60 3″ tubes; 1 60″ x 16′, 52 4″ tubes.	2	2	2	80,85	78,105	775,1,030	0	85–90
192	do		do	72″ x 16′, 84 4″ tubes	1	1	1	125	165	1,650	0	80
193	do			48″ x 16′, 36 3½″ tubes	2	2	2	50	63	625	0	80
194	do	12–15		2 72″ x 16′, 72 4″ tubes; 2 78″ x 18′, 84 4″ tubes.	4	3	3	115,150	156,200	1,560,2,000	0	85
195	Hand operated	15	2 times in 10 hours	72″ x 18′, 100 3½″ tubes	2	2	2	150	194	1,940	0	100
196	Automatic	12–15	4 times in 24 hours	72″ x 16′, 84 4″ tubes	2	2		100	166	1,655	4	90–100
197	do		Once in 10 hours	60″ x 16′, 72 3½″ tubes	2	2	1	100	124	1,240	0	80
198	do		Once in 14 hours	1 66″ x 18′, 54 4″ tubes; 1 66″ x 16″, 54 4″ tubes.	2	1	1	75	120,107	1,200,1,065	0	100
199	do	15–18	4 to 6 times in 24 hours.	78″ x 18′, 154 3″ tubes	6	6	6	184	257	2,565	0	95
200	do	12–16	4 times in 24 hours	84″ x 18′, 104 4″ tubes	4	4	4	215	229	2,290	0	125
201	do	12–15	3 to 4 times in 24 hours.	78″ x 18′, 104 4″ tubes	4	3	1	200	231	2,310	0	125
202	do	15–18	4 to 6 times in 24 hours.	78″ x 18′, 154 3″ tubes	4	4	4	184	257	2,565	0	95
203	do		6 times in 12 hours	4 72″ x 17′, 100 3½″ tubes; 1 72″ x 15′, 94 4″ tubes.	5	4	4	125	183,174	1,830,1,740	0	115
204	do	15–18	Every 4 to 6 hours	72″ x 16′, 72 4″ tubes	4	4	4	125	144	1,440	0	80
205	do	15	3 times in 24 hours	18′ long	3	2	3	2 80,1 100			0	100
206	do			60″ x 18′, 48 4″ tubes	2	1	1	75	106	1,060	0	60–80
207	do	12–18	4 to 6 times in 24 hours.	3 72″ x 18′, 72 4″ tubes; 1 60″ x 18′, 54 4″ tubes.	4	3	3	3 150,1 125	3 177,1 134	1,770,1,340	0	90
208	Hand operated	12	6 times in 24 hours	1 72″ x 16′, 72 4″ tubes; 2 72″ x 16′, 90 3″ tubes; 1 72″ x 16′, 92 3″ tubes.	4	4		125	142,134,136	1,420,1,335, 1,360	0	60–75
209	do	12–15	8 times in 24 hours	72″ x 16′, 92 3″ tubes	4	4		125	136	1,360	0	90–100
210	do	12	6 times in 24 hours	do	3	3		125	136	1,360	0	60–75
211	Automatic	15–18	2 times in 12 hours	72″ x 18′, 70 4″ tubes	2	2	2	150	156	1,550	0	100
212	do		7 times in 24 hours	72″ x 20′, 47 5″ tubes	2	2	2	125	145	1,450	0	90
213	do		2 times in 9 hours	60″ x 18′, 44 4″ tubes	1	1	1	75	92	920	0	100

TABLE 17.—*Details of observations at plants with underfeed stokers under return tubular boilers*—Continued.

No. of plant.	Kind.	Furnaces.						
		Number of stokers per boiler.	Dimensions (feet).					
			Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance at front of furnace from grates to heating surface (F).
			Average (A).	Minimum (B).				
188	Plain	1	15.5	12.5	5	6.3	0	3
189	.....do	1	15.5	12.5	6	6.3	0	3
190	.....do	1	15	12	5.5	6.3	0	3
191	.....do	1	13, 15	10, 12	5	6.3	0	2.5
192	.....do	1	15	12	6	6.3	0	2.75
193	.....do	1	16	13	4	6	0	.....
194	.....do	1	15, 17	12, 14	6, 6.5	6.3	0	2.5
195	.....do	1	16.5	14	6	6.3	0	2.5
196	.....do	1	15	12	6	6.3	0	3
197	.....do	1	15	12.5	5	6.3	0	3
198	.....do	1	17, 15	14, 12	5.5	6.3	0	3
199	.....do	1	17	14.5	6.5	6.3	0	3
200	.....do	1	17	14	7	6.3	0	3.25
201	.....do	1	17	14.5	6.3	6.3	0	3
202	.....do	1	17	14.5	6.5	6.3	0	3
203	.....do	1	16, 13	13.5, 12.5	6	6.3	0	3
204	.....do	1	15	12.5	6	6.3	0	3
205	.....do	1	17	14	6	6.3	0	2.5
206	.....do	1	18	15	5	6	0	.....
207	.....do	1	17	14.5	7.5	6.3	0	3.75
208	Dutch oven	1	19.5	16.5	6	6.3	4.5	2
209	Plain	1	20	17	6	6.3	4	2.3
210	Plain and Dutch oven	1	14.5, 19.5	11.5, 16.5	6	6.3	0, 4.5	2.5, 2
211	Plain	1	17	14	6	6.3	0	3
212	.....do	1	19	16	6.2	6.3	0	3
213	.....do	1	16.5	14.5	5	6.3	0	3

TABLE 17.—*Details of observations at plants with underfeed stokers under return tubular boilers*—Continued.

No. of plant.	Kind.	Draft and pressure.						Smoke records.						
		Readings (inches of water).												
		Pressure in ash pit.	Draft.					Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for one hour (minutes).			Average percentage of black smoke from observations.	Load during observations.
			Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
188	Chimney and forced.	.....	0.12–0.14	.....	.....	[a] 0.52	.....	Average conditions; dampers open.	1	60	1	2	47	7.7	Average.
189	do	2.5 –3	.....	.....	.....	.....	0.60	Dampers wide open.	1	60	0	0	58	.6	Light.
190	do	1.35, 1.75	.04– .20	.....	.....	.....	.40	Average conditions; dampers open.	1	62	0	0	46	12.7	Average.
191	do	1.40, 1.50	.29– .30	.....	0.40	.....	.....	do	1	60	6	0	49	13.8	Do.
192	do	2.55	.36	.....	.....	.....	.56	do	1	60	0	0	47	3.1	Light.
193	do	1.25	.13– .20	.....	.....	.27	.....	Fan running at maximum speed.	1	40	0	0	47	3.0	Do.
194	do	1.5	.20– .46	.....	.....	0.28–.46	.70	.....	1	600	0	0	58	.5	Average.
195	do	.....	.21– .22	.....	.40	.....	.50	.....	1	60	0	0	56	2	Do.
196	do	.75	.22– .28	.....	0.26– .36	.....	.54	.....	1	60	0	0	60	0	Heavy.
197	do	1.45	.28– .29	.....	.32– .37	.....	.....	.....	[b]	[c]	0	0	60	0	Do.
198	do	1.70	.39– .41	.....	.....	.....	.90	Average conditions; damper open.	1	60	0.5	1	55	3.7	Average.
199	do	2	.10– .13	.....	.17– .24	.....	.30	.....	1	60	0	0	53	1	Do.
200	do	2.5 –3	+.28 to –.06	.....	+.30 to –.04	.....	.54	.....	1	60	0	0	50	1.7	Light.
201	do	1.5	.50	.....	.50	.....	.50	.....	1	60	0	0	60	0	Average.
202	do	1.5	.16– .24	.....	.25– .28	.....	.....	.....	1	60	0	0	58	.7	Do.
203	do	1	+.04 to –.02	.....	+.12 to –.04	.54	.....	.....	1	300	0	0	59	.5	Do.
204	do	2	.06– .16	.....	.11– .25	.....	0.13–.30	.....	1	60	0	0	58	.7	Do.
205	do	1.25–1.50	.15– .18	.....	.17– .18	.....	.35	.....	1	60	0	0	59	.3	Heavy.
206	do	.90–1.10	.12	.....	.....	.30	.40	Damper open	2	55	0	0	54	2.1	Light.
207	do	2.25	.10– .15	.....	.....	.34	.40	.....	1	600	0	0	57	2.1	Average.
208	do	.....	.02– .12	.....	.....	.10–.22	.44	.....	[b]	[c]	0	0	[d]	.....	Heavy.
209	do	.5	.08– .13	.....	.11– .20	.....	.....	.....	1	60	0	2	55	3.7	Do.
210	do	1.6–2.1	0– .08	.....	.....	.16–.22	.....	.....	[b]	[c]	0	0	[d]	.....	Do.
211	do	1.4	.46– .55	.....	.46– .55	.....	.65	.....	1	60	0	0	60	0	Average.
212	do	2.5–2.75	.17	.....	.....	.30	.37	One boiler in service; damper open.	2	61	0	0	55	1	Do.
213	do	.....	.....	.....	.....	.....	.....	.....	1	60	0	0	60	0	Do.

[a] Near stack. [b] Several. [c] Various lengths. [d] See remarks.

TABLE 17.—*Details of observations at plants with underfeed stokers under return tubular boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
188	15	3.5 x 3.5	Near stack	0	110	a 3.25	10.5	
189	15			2	200	a 8	50.3	
190	0			0	85	a 5.5	23.7	Observations include a cleaning of fires.
191	8			1	140	a 3.1	7.45	Distance to heating surface 2.5 feet.
192	0			0	65	a 3	7.07	
193	5			1	80			Large combustion chamber. Fan running at maximum speed when pressure in ash pit was measured. Stokers not run continuously on light load.
194	9			1	95	a 5.5	23.8	Boilers arched over top for gas passage.
195	24			1	80	a 3.5	9.6	
196	17			0	80	a 4.25	14.1	Some smoke when cleaning fires, usually about two minutes of 60 per cent black.
197	31			2	97	4 x 4	16	
198	30			1	130	a 3.5	9.6	Large combustion chamber.
199	6			0	100	7.5 x 7.5	56.25	Boilers arched over top for gas passage.
200	70			3	150	a 6	28.3	Cleaned fire during smoke observations.
201	13			0	200	a 4	12.56	
202	5			0	70	5 x 5	25	Boilers arched over top for gas passage.
203	32			1	90	a 6.5	33.2	
204	5			2	65	3 x 3	9	Two similar stacks.
205	6			0	75	3 x 3	9	
206	16			1	100	5 x 5	25	Coal not well burned and refuse usually refired. Stoker not run continuously on light load. Fire sometimes requires poking; then stack is not so good as recorded observation. Stack rests on front of boiler. Coal nearly all slack.
207	13			1	125	a 4.5	15.9	Boilers arched over top for gas passage.
208	0			0	100	a 4	12.56	No smoke except when cleaning fires; then each furnace gives off 60 per cent black (or lower) smoke for about half a minute.
209	16			1	75	a 4	12.56	
210	9			1	75	a 4	12.56	Do.
211	45			2	120	5 x 5	25	Each furnace gives off about 40 per cent black (and lower) smoke for about one minute.
212	0			1	75	a 3.3	8.7	
213	2			1	55	2.5 x 2.5	5	Burned 728 pounds coal per stoker per hour. Distance to heating surface, 2.75 feet. Some smoke when cleaning fire.

a Diameter.

SUMMARY.

The underfeed stoker affords a means of increasing both the economy and capacity of plants which by gradual growth have added so many boilers to a single stack that the draft capacity of the stack has been exceeded, and natural draft does not supply the necessary amount of air to permit the required amount of coal to be burned with high efficiency.

A very much smaller stack will suffice with the underfeed stoker than with some other devices, as it is only necessary to have enough stack draft to carry away the gases of combustion, all the air necessary for burning the coal being forced through the fire.

It will be seen that this stoker is meeting with most success in districts where low-ash coal is used.

The notes show that the greatest difficulty in keeping down smoke came when cleaning fires, but in general at the plants visited there was little trouble on this account.

In this stoker the ash accumulates at either side of the retort. The furnace temperature is so high that most of the ash fuses and is pulled out of the furnace in large pieces. Both for this reason and to permit complete combustion of the fuel it is advisable to have the dead plate on which the clinkers accumulate of sufficient width to permit cleaning fires without breaking up the fuel bed.

SMOKE PREVENTION AT BOILER PLANTS WITH GREAT VARIATIONS OF LOAD.

The data already presented show that bituminous coals high in volatile matter can be burned without smoke. Smokeless combustion at large plants carrying loads that fluctuate widely, where boilers over banked fires must be put in service quickly and fires forced to the capacity of the units, is no less possible. The accompanying load diagram (fig. 24) shows the variations in boiler horsepower in service and in power output at a plant of about 10,000 horsepower. The sudden increase in output and in boilers in service between 5.30 and 8.30 a. m. and the heavy peak load in the early evening are strikingly brought out. Yet the stacks at this plant, though frequently watched at the time of peak load, were quite clean. No better demonstration than this of what can be done by proper equipment, efficient labor, and intelligent supervision could be given.

HAND-FIRED FURNACES.

GENERAL STATEMENT.

None of the problems of combustion have received more experimental treatment than the burning of coal in hand-fired furnaces. Hundreds of devices for smokeless combustion have been patented,

but almost without exception they have proved failures. This record may be explained by the fact that many of the patentees have been unfamiliar with all the difficulties to be overcome, or have begun at the wrong end. Numerous patents cover such processes as causing the waste gases to reenter the furnace, and schemes for collecting and burning the soot are legion. So many manufacturers who have been looking for some cheap addition to a poorly constructed furnace

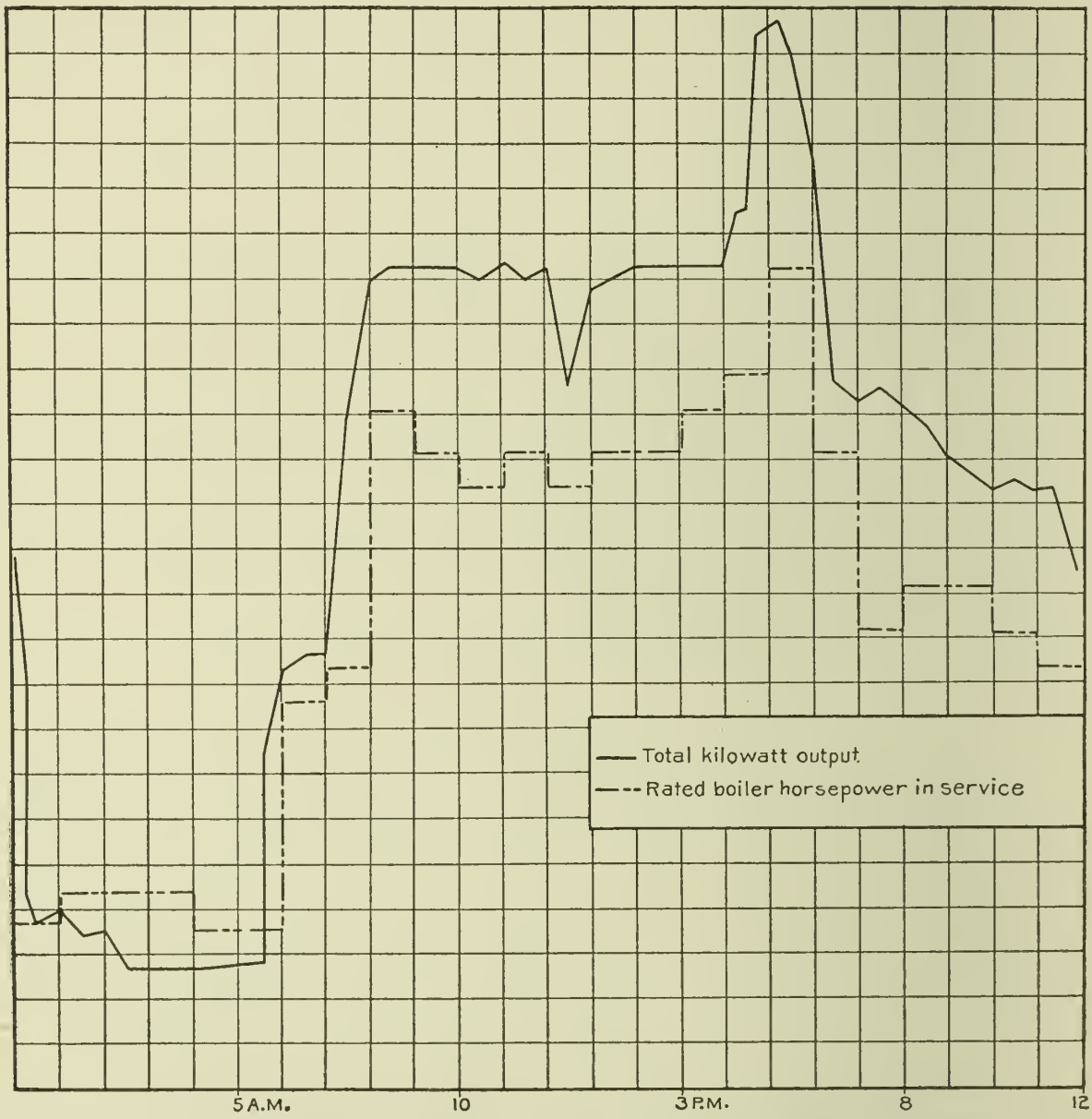


FIGURE 24.—Load and boiler-service chart of large power plant with mechanical stokers. The total rated boiler horsepower used to supply the demand for power varied from about 2,000 to 12,000. This plant is absolutely smokeless.

to make it smokeless have experienced inevitable failure that the work of educating the public to rid cities of the smoke nuisance has been hard, long, and only partly successful.

The total number of steam plants having boilers fired by hand is far greater than the total of plants with mechanical stokers, but if the comparison is based on total horsepower developed the figures show less difference. Particularly is this true in sections of the Middle West, where mechanical stokers are generally used at large plants.

As a general rule hand-fired plants do not have proper furnaces, and methods of operation are far from conducive to good combustion. Coal is usually fired in large quantities, and little opportunity is given for the air and gases to mix before the heating surface is reached and combustion is arrested. In all the hand-fired plants visited success in smoke prevention has been obtained chiefly by careful firing. The coal was thrown on often in small quantities; the fire was kept clean, enough ash to prevent the passage of air through the fire never being allowed to collect on the grate; and more air was supplied at firing than after the volatile matter had been distilled. Even with such precautions the plants might have made objectionable smoke at times but for the fact that usually some method was employed for mixing the gases and air before they reached the heating surface.

COKING FURNACE.

One pattern of furnace that requires less attention from the fireman and less care in operating than the usual hand-fired types was found at several plants. This is known as the coking furnace, which in its earliest form was the invention of James Watt. With this furnace large charges of coal may be fired at one time. The coal is shoveled or fed from magazines to a dead plate at the mouth of the furnace, where the volatile compounds distill, and the coal is later pushed back. Unfortunately, in the model of this furnace generally used the magazines are open after the coal on the dead plate has burned down, so that the coal is consumed with a large excess of air.

STEAM JETS.

A clean stack with hand firing is not as good evidence of efficient operation as it is with almost any type of mechanical stoker, because of the special devices used with hand-fired boilers to prevent smoke. Steam jets are the most common of such devices. Usually they are not automatic, and at many plants they are allowed to run longer than is necessary or else are not used at all. Any steam jet that will so mix the gases and air at the times of greatest need, when coal is fired, as to prevent smoke will, if allowed to run continuously, probably waste more of the energy in the coal than it will save. At the same time a steam and air admission device allows a regulation which, if properly made, will keep a stack clean and save coal.

The steam jet is found in an improperly designed furnace or in one where the air supply is too small. It is an expensive device, all conditions being considered. The only purpose it can serve is to mix the air and gases intimately and prevent the combustible gases from coming too quickly into contact with the heating surface. The claims sometimes made that the use of a steam jet will increase the thermal value of the fuel are erroneous.

It takes the same amount of heat to dissociate a pound of steam into hydrogen and oxygen as is given off when a pound of steam is formed by the union of hydrogen and oxygen. Moreover, the fact must not be overlooked that to burn hydrogen in the average furnace is extremely difficult, and therefore if some steam were dissociated by a jet it is probable that part of the hydrogen would escape to the stack unburned. The same quantity of oxygen that is formed by the dissociation of a pound of steam would be required to burn enough hydrogen to form another pound of steam, therefore there would be no oxygen available from dissociation to burn the coal.

In a water-gas plant, sometimes cited by makers of steam-jet attachments, the heat required to dissociate the steam is supplied by the coke and is later utilized when the gas is burned. The process is as follows: Air is blown through the fuel bed until combustion is fairly well started. The air is then shut off and steam is blown through; this is dissociated, the fuel loses its heat and if the operation continues too long the fire goes out; but after a certain length of time the steam is turned off and air is passed through until the fuel bed is in condition to give up more heat. Then steam is turned on again and the process repeated. After several hours of operation several thousand cubic feet of gas have been formed from the union of the dissociated oxygen of the steam with the glowing carbon of the coke, but there has been no gain in thermal units.

Another fact to be remembered in using steam jets is that all steam entering the furnace must be heated to stack temperature, and the heat required for this is supplied from the coal.

As most air is required in a furnace at the moment of firing fresh coal, and the requirement diminishes as the volatile matter in the coal is distilled, steam jets need close regulation for good economy. To make this regulation independent of the fireman several devices for automatically turning the steam on and off have been patented. Figure 25 illustrates one of these devices at a furnace under a water-tube boiler, and figure 26 gives a section through a return tubular boiler with similar equipment. Opening the furnace door turns on the steam, and a dash pot suitably connected shuts off the jets after a short interval.

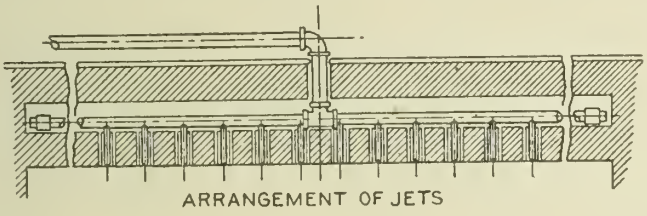
MIXING DEVICES.

There is no question as to the value of mixing the air and gases in a hand-fired furnace, and if the mixing could be done by some effective arrangement of fire-brick piers the losses resulting from the use of steam jets would be avoided, but to build arches and piers that will stand the intense heat from intimate mixing and combustion has proved a difficult matter. Moreover, the piers and arches take

up room and diminishing the space in a furnace will usually reduce the available furnace draft, so that less coal can be burned even though there is more perfect combustion. The easiest and most nearly perfect solution of the problem is a mechanical stoker properly set under the boiler.

DETAILED DESCRIPTION OF PLANTS.

During the field investigations 71 hand-fired plants run without the emission of dense smoke were visited. The types of boilers installed at these plants were as follows: Return tubular, 44; water-tube, 22;



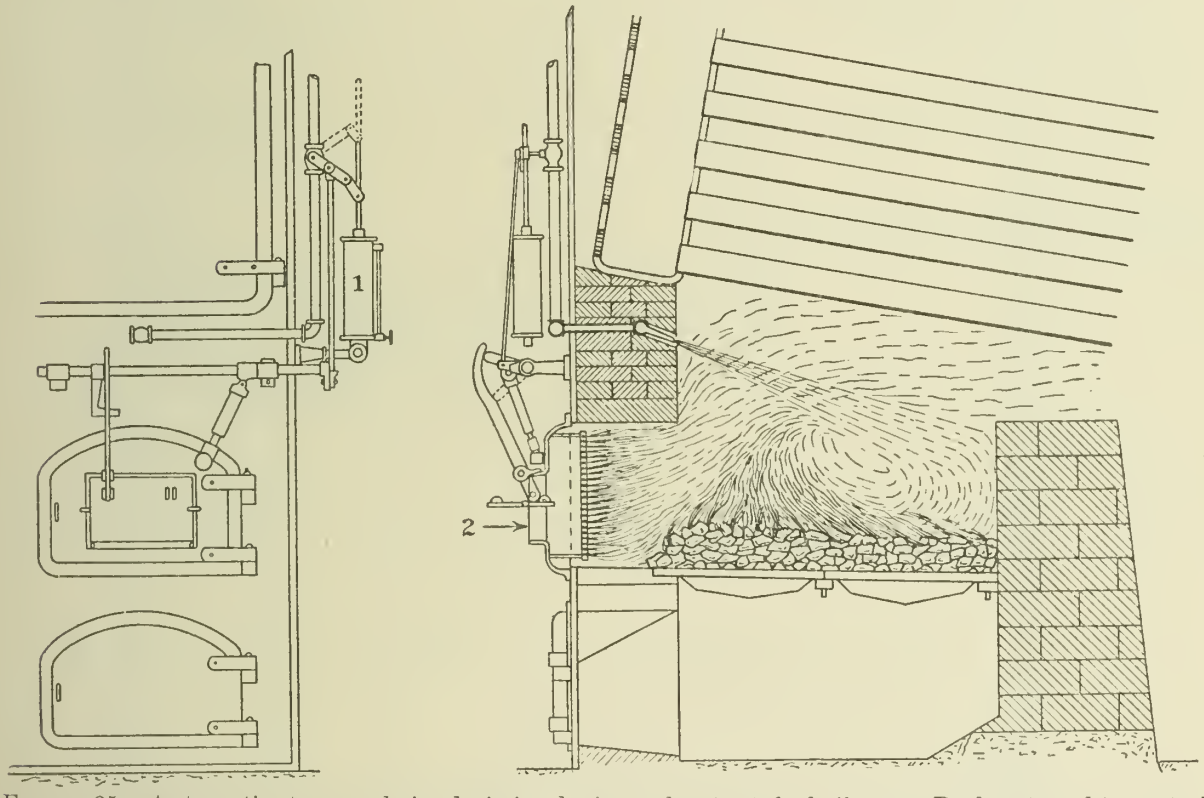


FIGURE 25.—Automatic steam and air admission device and water-tube boiler. 1, Dash pot used to control length of time steam jets are in operation; 2, air admission through furnace doors.

Scotch marine, 5. Tables 20 to 25 give all the essential data that could be collected regarding these plants.

Plants with water-tube and Scotch marine boilers.—Hand-fired furnaces operated under water-tube or Scotch marine boilers were found at 27 plants. These furnaces were of the following patterns: Plain, Dutch oven, Burke, Dorrance, down-draft, Puddington, and twin arch. Brief descriptions of three of these, including the down-draft pattern, are appended, and some of the others are described in the discussion of hand-fired furnaces with return tubular boilers (pp. 117–124).

One of these furnaces is virtually a Dutch oven with a long, rearward-sloping arch that entirely covers the grate and projects into

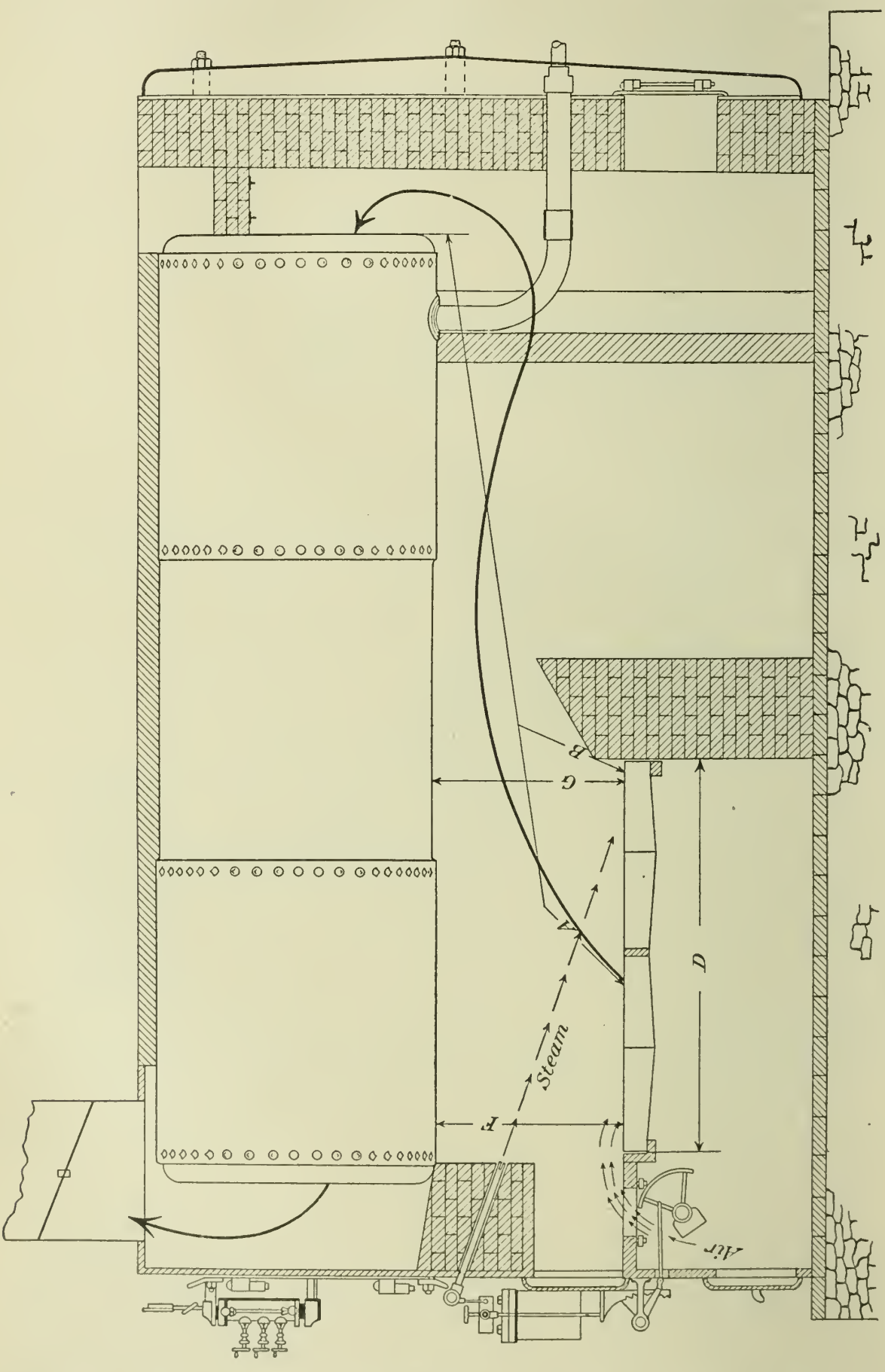


FIGURE 26.—Automatic steam and air admission device and return tubular boiler.

the space back of the bridge wall. The grate also has a rearward slope. The accompanying illustration (fig. 27) of one of these furnaces

under a Babcock & Wilcox boiler shows how the travel of the burning gases is lengthened.

The distinguishing feature of the down-draft furnace is an upper grate, which may be formed of tubes through which water circulates,

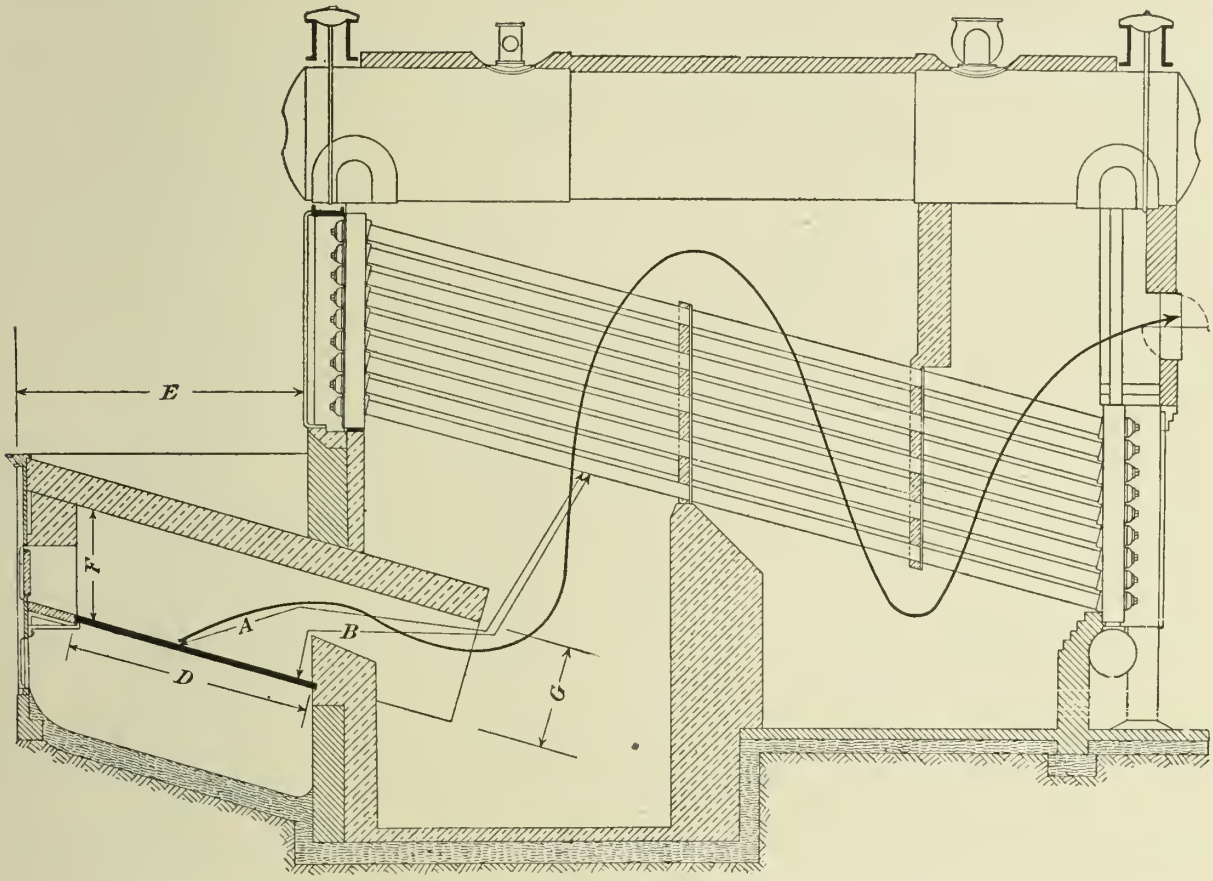


FIGURE 27.—A hand-fired furnace and Babcock & Wilcox boiler.

connected to headers and supported by lugs. The fresh coal is thrown on this grate, whence, after partial burning, it falls to a grate of ordinary construction a foot or more below, where combustion is com-

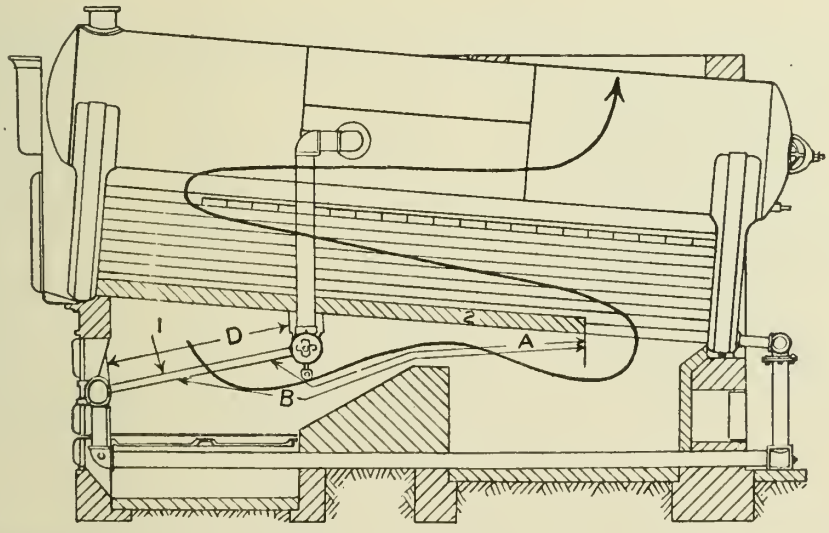


FIGURE 28.—Down-draft furnace and Heine boiler. 1, Water-tube grate; 2, C tile on lower row of tubes, forming a tile-roof furnace.

pleted by the excess of air drawn through the upper and lower grates. The air and the distilled gases from the fresh coal are heated and intimately mixed in passing through the fuel bed, facilitating

combustion in the space between the grates. One of these furnaces under a horizontally baffled Heine boiler is represented in figure 28.

The third furnace has back of the bridge a fire-brick wall with two arched openings at its base separated by a projecting angle. The

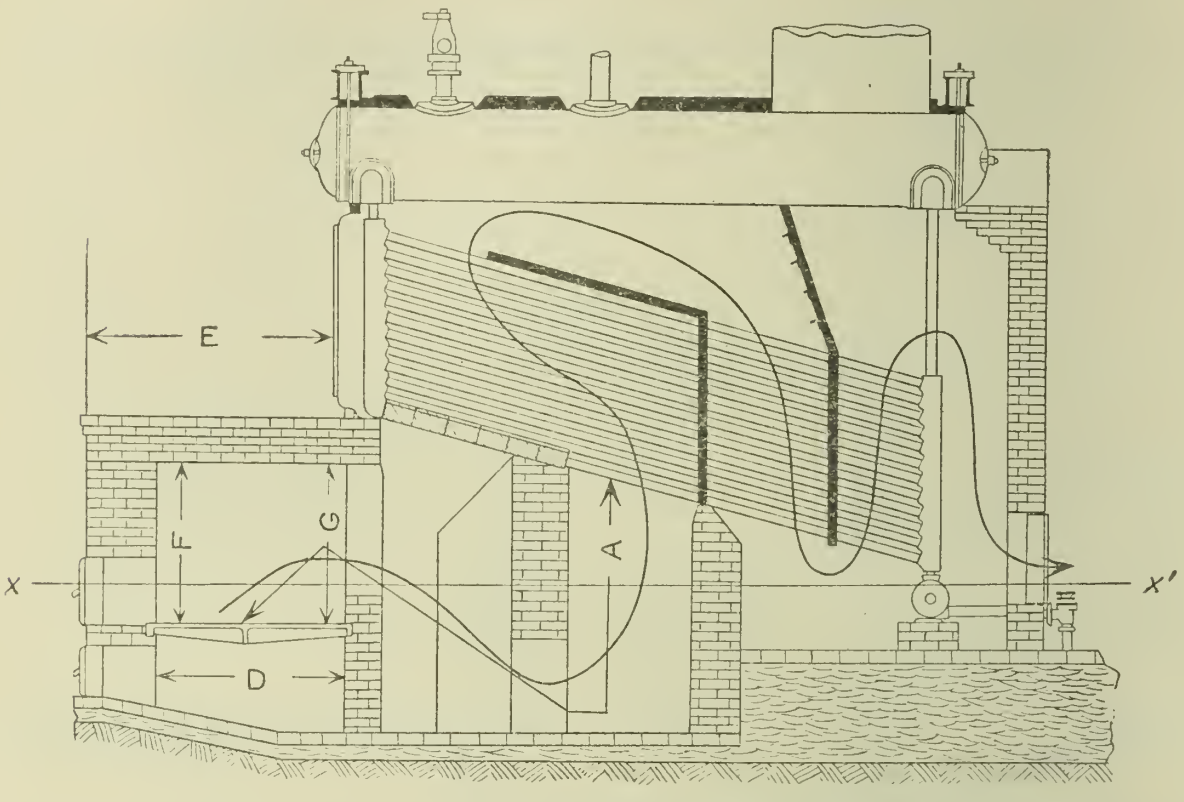


FIGURE 29.—A hand-fired furnace and Babcock & Wilcox boiler, elevation. *X–X'*, Line of sectional plan, figure 30.

long minimum distance from grate to first tube heating surface is shown by figure 29. The plan of the furnace (fig. 30) and the cross section (fig. 31) show the construction of the mixing wall.

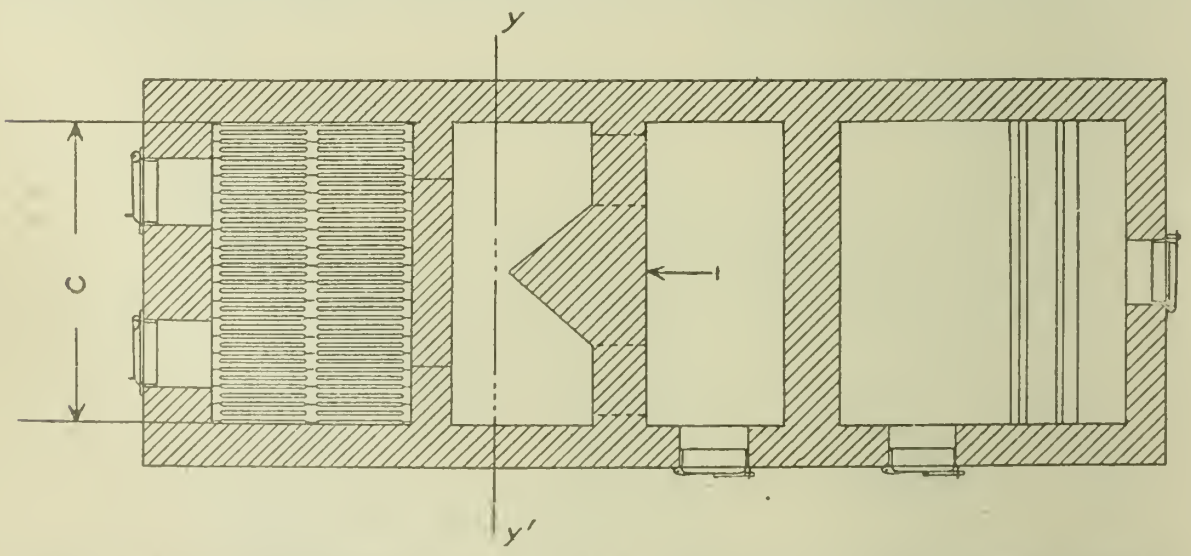


FIGURE 30.—A hand-fired furnace, plan along line *X–X'*, figure 29. *y–y'*, Line of cross section, figure 31.

These 27 plants ranged in size from 75 to 1,500 horsepower. Seven were equipped with steam-jet devices. Ten had a variable load and 17 a uniform load. At 9 plants the coal supplied was either run-of-mine, egg, or lump. The coal as fired burned per square foot of grate

surface per hour varied from 10.8 to 40.4 pounds and averaged 23.9 pounds. The average ratio of heating surface to grate surface was 49.6 to 1, the lowest being 26 to 1 and the highest 73 to 1. Thirty-five per cent of the furnaces were installed under boiler units of 150 horsepower or less and 50 per cent under units of 200 horsepower or less. Forty-four per cent of the plants had either rocking or dumping grates. All plants except one with induced and one with forced draft ran on natural draft. Thirteen of the plants were fired by the spreading method, 8 by the alternate method, and 3 by the coking method. The kind of coal used and the average depth of fire are summarized in the following table:

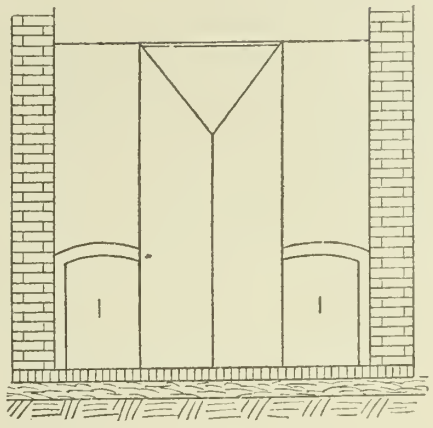


FIGURE 31.—A hand-fired furnace, cross section along line *y–y'*, figure 30. 1, Openings in mixing structures.

TABLE 18.—*Kind of coal and depth of fire at plants with hand-fired furnaces under water-tube and Scotch marine boilers.*

Kind of coal.	Number of plants.	Average depth of fire.	Kind of coal.	Number of plants.	Average depth of fire.
		Inches.			*Inches.*
Illinois	14	7	Pennsylvania	1	11
Indiana	2	8	West Virginia	4	7
Maryland	2	15	Miscellaneous	3	8
Ohio	1	4			

Details regarding type of furnace, kind of coal, amount consumed, draft, furnace setting, etc., are summarized below:

TABLE 19.—*Summary of various observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers.*

Type of boiler.	Kind of furnace and number of plants.[a]	Kind of coal.	Furnace draft.	Coal burned per square foot of grate surface per hour, average heavy load.	Percentage of rated boiler horsepower developed, average heavy load.[b]	Distance from grates to tube-heating surface.		Distance from front of furnace to front of boiler	Vertical distance from grate to arch or heating surface.	Black smoke.
						Average.	Minimum.			
			Inch water.	*Lbs.*		*Ft.*	*Ft.*	*Ft.*	*Ft.*	*P.ct.*
Babcock & Wilcox.	Dutch oven 2, plain 1, twin arch 1.	Illinois and West Virginia.	0.24	20.5	107	11	8	4.8	3.1	4.5
Heine	Dorrance 1, Hawley 3, Puddington 1.	Illinois, Maryland, Ohio, and West Virginia.	.41	30.5	103	8.6	6.2	0.	2.6	4.3
Scotch marine	Burke 2, Hawley 1, plain 2.	Illinois and Indiana.	.21	19.7	84	4.2	3.0	4.3	1.7	4.0
Miscellaneous	Dorrance 3, Dutch oven 1, Hawley 3, plain 4, Burke 2, twin arch 1.	Illinois, Indiana, Maryland, Pennsylvania, and West Virginia.	.30	24.5	104	9.4	7.2	2.9	2.9	4.5

[a] One plant has both Hawley and plain furnaces.
[b] Boiler rated on 10 square feet of heating surface per horsepower.

The draft observations may be briefly summarized thus:

Average furnace draft, 25 plants, 0.29 inch of water; least, 0.07 inch; most, 0.60 inch. Average draft at rear of boiler, 11 plants, 0.54 inch, least, 0.32 inch; most, 0.70 inch. Average draft at base of stack, 19 plants, 0.75 inch, least, 0.50 inch; most, 1 inch. From these readings were deduced the following approximate draft averages: Approximate average draft in furnace, 0.30 inch of water; at rear of boiler, 0.55 inch, at base of stack, 0.75 inch. This gives an average drop of 0.25 inch of water through the boiler and of 0.20 inch from the boiler to the base of the stack.

Details of the observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers are given in Table 20.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers.*

No. of plant.	State.	Device used to facilitate combustion.	Total builder s rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
214	Illinois	None	450	Washed	Carterville, Ill	No. 5	$2.10	
215	Ohio	Steam jet	825	New River	West Virginia	Slack		
216	do	do	100			Nut and slack		
217	New York	None	80			Slack		1,400
218	Illinois	do	900	Washed	Carterville, Ill	Nos. 4 and 5		
219	Maryland	Steam jet	424	Somerset big vein	Maryland	Run of mine	2.80	1,940
220	Ohio	Air admission	325	Massillon	Ohio	Slack	2.00	5,000
221	do	None	500	New River	West Virginia	Nut and slack	2.50	
222	do	Steam jet	200	Pocahontas	do	Screened lump	3.60	
223	Illinois	None	750	Washed	Illinois	Nut and pea		
224	do	do	711	do	Carterville, Ill	Nos. 2 and 5		
225	do	do	200		do	No. 2		
226	do	do	1,500	Miami lump	Indiana	1-inch screenings	2.25	
227	Michigan	do	500	Red jacket		Run of mine	2.85	1,550
228	Illinois	do	900	Washed	Carterville, Ill	Nos. 4 and 5	$2.60–2.65	
229	Missouri	Steam jet	900	Staunton	Illinois	Lump	2.05	6,420
230	Illinois	None	600		do	1½-inch screenings	1.80	
231	do	do	540	Washed	do	No. 4	2.65	
232	Missouri	do	500	Staunton	do	Lump	2.05	
233	Illinois	do	450		do	1-inch nut		
234	do	do	450		do	3-inch screenings	2.60	
235	do	do	856	Majestic	Near Carterville, Ill	No. 1 nut		
236	do	do	200	Buckhorn	do	Egg	2.85	
237	do	do	75	Block	Indiana	Run of mine	3.60	
238	Maryland	Steam jet	765	Georges Creek	Maryland	do	3.02	
239	New York	None	600		Pennsylvania	Slack	2.00–2.40	9,800
240	Ohio	Steam jet	150		West Virginia	Run of mine	2.00	

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant	Load.			Rating.							
				Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
	Requirement.	Nature.	Character.	Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
214	Power, light, and heat	Variable	Offices and manufacturing	10	11	10	9	30.6	27.8	140	147	5
215	Power and light	Uniform	Office building	12	10	12	10	17.1	17.1	74	68	4.5
216	Power	do	Factory	9.5	1.9			17.4		71	80	5
217	Power, light, and heat	do	Transfer company	12	2	12	1	16.7	12.5	143	186	4.5
218	do	do	Hotel	24	19	24	16	35	32.1	100	106	5
219	Power and heat	do	Post-office	12	6.2	12	4.8	18.3	16.3	115	109	4.5
220	Power and light	Variable	Commercial	17	15	17	7.4	36.8	27.5	95	109	5
221	do	Uniform	Office building	12	7.5			32		140	125	4
222	Power, light, and heat	do	Post-office	17	4.3	17	3.5			63	63	4
223	do	Variable	Offices and theater	24	20	24	8	17	16	90	66	5
224	do	do	Hotel	24	22	24	15.5	25.5	21.5	97	80	5
225	do	do	Store building	11	3.5	14	3.25	14	10	81	64	5
226	do	Uniform	Waterworks	24	60	24	60	31	31	100	132	5
227	do	do	Laundry	12	4.9	12	3.7	10.8	9.5	50	36	4.5
228	Power and light	do	Office building	8	12.5	24	20	33.9	26	93	104	5
229	Power, light, and heat	do	Commercial	17	12			12.9		57	47	5
230	Light and heat	Variable	Brewery	24	12	24	15	16.2	13.4	76	80	5
231	Power and heat	Uniform	Office building	10	5	10	3	31	25	111	111	5
232	Power, light, and heat	do	Factory	10	8.8	10	6	34	28.5	170	141	5
233	do	Variable	Office building	16.5	6	10	3	29	27	97	97	5
234	do	Uniform	Hotel	18	16	18	16	32	32	112	118	5
235	do	Variable	Office building	11	18	11	8	40.4	40	160	153	5
236	Power and heat	Uniform	do	12	6.5	12	5	20	18	108	108	5
237	Power, light, and heat	Variable	Printing office	10	3	10	2	28	24		160	5
238	do	do	Hotel	17	14	17	14	14.2	14.2		79	4.5
239	do	Uniform	Office building	17	20	17	17	14.7	13.3	60	79	5
240	do	do	Store building	11	2.5	11	2.5	12.7	12.7		61	5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

	Stoking.					Boilers.								
No. of plant.	Method of firing.	Frequency of firing (minutes).	Coal fired at each firing per boiler (pounds).	Thickness of fire (inches).	Frequency of cleaning fire.	Type.	Size.	Number installed.	Number used to carry— Average heavy load.	Number used to carry— Average light load.	Builder's rated horsepower.	Horsepower.[a]	Heating surface (square feet).	Superheating surface.	Steam pressure at gage.
214	Alternate	(b)	75–90	10–12	Once in 10 hours	Babcock & Wilcox water-tube.	84 4″ x 16′ tubes	3	2	2	150	157	1,570	0	165
215	do	15	65	8–10		do	120 4″ x 18′ tubes	3	2	2	275	252	2,520	0	150
216	Spreading	7–12	60–90	4–6		do	54 4″ x 18′ tubes	1	1	1	100	113	1,130	0	90
217				6–8		do	32 4″ x 14′ tubes	2	1	1	40	52	520	0	80
218	Alternate	(b)	45	6–8	3 times in 24 hours.	Heine water-tube.	170 3½″ x 18′ tubes, 2 36″ drums.	3	1	1	300	319	3,185	0	150
219	Spreading	(b)	250–400	(b)	2 to 3 times in 12 hours.	do	54 3½″ x 18′ tubes, 1 36″ drum.	4	2	2	106	106	1,000	0	120
220	do	15	150–180	3–4	3 to 4 times in 17 hours.	do	176 4″ x 18′ tubes	1	1	1	325	370	3,700	0	105
221	do	(b)	(b)	6–8		do	116 3½″ x 19′ tubes, 1 40″ drum.	2	1	1	250	224	2,240	0	150
222	do	20	270–370		Once in 24 hours	do	58 3½″ x 18′ tubes	2	2	2	100	100	1,000	0	120
223	Coking	(b)	(b)	(b)	3 times in 24 hours	Scotch marine	84 4″ tubes, 9 3/16′ x 18′ shell.	3	2	1	250	175	1,750	0	100–110
224	Spreading	(b)	60	6–8	do	Inverted Scotch marine.	94 3″ tubes, 94″ shell.	3	2	2	237	190	1,900	0	145
225	Coking	(b)	(b)	(b)	Once in 11 hours	Scotch marine	44 3½″ x 15′ tubes, 78″ shell.	2	2	2	100	75	746	0	90–100
226	Spreading	18–25	350–400	8	6 times in 24 hours	do	138 4″ x 12′ tubes, 10′ shell.	6	4	4	250	190	1,900	0	130
227	do	12		5–6	Once in 12 hours	do	2 38″ flues, 2 42″ flues.	2	2	2	200, 300	142, 225	1,423, 2,250	0	100
228	Alternate	4–6	50–70	6	Once in 8 hours	Cahall horizontal water-tube.	160 4″ x 18′, 2 42″ drums.	3	2	2	300	335	3,350	0	135
229	Spreading	15–30	150	10	2 times in 12 hours.	O'Brien water-tube.	140 x 18′ tubes	3	2	1	300	250	2,500	0	140
230	do	(b)	400–500	c 8	3 times in 24 hours.	Cahall horizontal water-tube.	162 4″ x 18′, 126 4″ x 18′.	2	1	2	250, 350	264, 340	2,640, 3,400	0	120
231	Alternate	5–7	40–60	6–8	Once in 8 hours	Detroit water-tube	96 4″ tubes, 1 30″ drum.	3	1	1	180	180	1,800	0	125

[a] Boiler rated on 10 square feet of heating surface per horsepower. [b] Variable. [c] On top grate.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant.	Stoking.					Boilers.									
	Method of firing.	Frequency of firing (minutes).	Coal fired at each firing per boiler (pounds.)	Thickness of fire (inches).	Frequeney of cleaning fire.	Type.	Size.	Number installed.	Number used to carry—		Builder's rated horsepower.	Horsepower.	Heating surface (square feet).	Superheating surface.	Steam pressure at gage.
									Average heavy load.	Average light load.					
232	Spreading...	20	100	11	2 times in 10 hours.	O'Brien water-tube.	113 3½″ x 18′ tubes.	2	1	2	250	207	2,070	0	140
233	Alternate....	(a)	30–35	3–4	.....do.....	Aultman & Taylor water-tube.	72 4″ x 18′ tubes, 1 36″ drum	3	1	1	150	150	1,500	0	90–110
234	.....do.....	10–15	60–75	4–5	3 times in 24 hours.	Detroit water-tube	110 3½″ x 14′ tubes.	3	2	2	150	158	1,575	0	120
235	.....do.....	(a)	45	3	.....do.....	Aultman & Taylor water-tube.	2 36″ drums.....	4	2	1	200, 228	188, 226	1,875, 2,260	0	125
236	Coking.....	(a)	(a)	.....	1 to 2 times in 12 hours.	Standard water-tube.	54 4″ x 16′ tubes, 36″ drums.	2	2	2	100	100	1,000	0	120
237	.....do.....	(a)	(a)	(a)	Once in 10 hours..	Stirling water-tube	.....	1	1	1	75	.....	.....	0	100
238	Spreading...	8–12	120–150	14–16	2 times in 24 hours.	Edgemoor water-tube.	.....	3	2	2	300, 165	.....	.....	0	150
239	.....	7	120–150	9–12	3 times in 24 hours.	Geary water-tube.	140 4″ x 16′ tubes..	4	3	3	200	260	2,600	0	135
240	Spreading...	10	50–90	5–6	2 times in 11 hours.	Stirling water-tube	144 3¼″ tubes.....	1	1	1	150	.....	.....	0	100

(a) Variable.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant.	Furnaces.									
	Number.	Kind of furnace.	Kind of grate.	Grate area per boiler [a] (square feet).	Dimensions (feet).					
					Distance from grates to tube-heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance at front of furnace from grates to coking arch or heating surface (F).
					Average (A).	Minimum (B).				
214	3	Twin arch	Shaking	36	17	14	3	6	5	2.3
215	3	Dutch oven	Flat	48.75	8.5	5.5	7.5	6.5	7	4.5
216	1	Plain	Rocking	23			3.8	6	0	
217	2	Dutch oven	Flat; hollow	20	7.5	4.5	3.3	6	7	2.5
218	6	Dorrance	Rocking	45.6	10	7	4	5.7	0	2.2
219	4	Hawley	Water-tube and flat	28.2	12	9	4.8	5.8	0	
220	1	Puddington	Flat	48	3	2.5	8	6	0	3
221	2	Hawley	Water-tube and flat	39	9	6	6.5	6	0	
222	2	do	do		9	6.5			0	
223	3	Burke	Rocking	48	8.5	5.5	8	6	7.75	
224	6	Corrugated flue	Flat	36	1.5	1.5	3	6	0	1.5
225	2	Burke	Rocking	23.6	7.5	5.5	5.25	4.5	6.25	
226	12	Hawley, down draft	Water-tube and flat	40	4	2	8	5	7.75	
227	4	Corrugated flue	Flat	38	[b] 1.6, 2	[b] 1.6, 2	[b] 3.2, 3.5	[b] 6, 5.6	0	[b] 1.6, 2
228	6	Dorrance	Rocking	46	12.5	9.5	4	5.75	6.5	2.5
229	2 Hawley 1 Plain		Water-tube and flat	55			10	5.5		
230	2	Hawley	do	59, 61.5						
231	3	Dutch oven and tile roof	Shaking	33.25	17	13.5	4.75	7	3.3	2.6
232	2	Hawley	Water-tube and flat	52			8	6.5	0	
233	3	Dorrance	Shaking	25	11	9	5	5	6.3	2.3
234	3	Twin arch	do	27.5	9	6.5	2.5	5.5	0	2.2
235	4	Dorrance	do	36, 47	11.5	8	[b] 5, 8, 6.7	6.2	6.5	[b] 3, 3.3
236	2	Burke	do	27	9	6.5	6	4.5	4.5	2
237	1	do	Rocking	21.3	11.5	9.5	4.75	4.5	5	
238	3	Plain	Flat	75, 41.25	4.5	4.5	[c] 10, 5.5	7.5	0	5.5
239	4	do	McClave flat	53.5	2.5	2	8.9	6	0	2.5
240	1	do	Flat	35.75	5	3	6.5	5.5	0	3

[a] In down-draft furnaces, area of upper grate only.

[b] First dimension applies to small boiler.

[c] First dimension applies to large boiler.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant.	Kind.	Draft. Readings (inches of water). Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.	Conditions under which readings were taken.	Smoke records. Number of observations.	Total length of observations (minutes).	Average for one hour (minutes). 100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.	Average percentage of black smoke.	Load during observations.
214	Chimney	0.38	0.46–0.50		0.72	0.78	Damper open, door in base of stack cracked.	2	128	0	0	54	3.4	Light.
215	do				.75		Damper partly closed	(a)	(b)	0	0			Average.
216	do	.18				.55	Damper open, ash-pit doors three-quarters closed.	(a)	(b)	0	0	55		Heavy.
217	do	.16	.32			.55		1	60	0	0	49	5.7	Light.
218	do	0.50–.53	.78		1.46		Damper open	4	262	2	1	52	5.3	Do.
219	do	.26–.38			0.56–.84		Damper partly closed	(a)	(b)	0	0			Heavy.
220	do	.16				.51		1	60	0	0	52	3.3	
221	do	.50			1.45		Damper and ash-pit doors open.	(a)	(b)	0				Do.
222	do	.55			.95		Dampers open	(a)	(b)	0	0			Do.
223	do	.16				1	Door at base of stack open	8	515	0	3	50	5	Light.
224	do	.22–.48			.96		Dampers open	4	272	0	0	52	3.1	Do.
225	do	.04–.09	.43		.74		Damper and ash-pit doors open.	1	60	0	0	60	0	Do.
226	do	.25–.40			.56–.64		Dampers open; ash-pit doors cracked.	1	60	1	3	47	7.9	Average.
227	do	.11–.17		0.37–0.40		.50		1	60	0	0	54	4.2	Heavy.
228	do	.27	.68			.90	Damper open	3	211	0	0	51	.3	Do.
229	do	.29	.54					1	60	0	0	49	5	Do.
230	do					0.75–.85	Dampers partly closed	2	114	0	2	40	6	Light.
231	do	.23				.85	Door in base of stack open	7	399	8	5	44	12.6	Do.
232	do	.54	.60				Ash-pit doors open	1	60	0	0	36	6.5	Do.
233	do	.36	.66		.94		Damper half open	2	150	0	0	60	0	Do.
234	do	.12	.47			.76	Dampers and ash-pit doors open.	4	187	0	0	60	0	Average.
235	do	.24–.25	.56			.78	Dampers open	4	272	0	0	56	4.2	Light.
236	do	.11–.12	.46–.47		.76		do	3	183	0	0	54	2.4	Do.
237	Induced	.09	c.45				Fan running at average speed.	1	60	0	0	60	0	Do.
238	Chimney	.60			.90		Dampers open	1						Average.
239	Forced	.22–.44	.32–.45		.92	1	Fan blast in ash pit	1	120	0	0	30	11.8	Light.
240	Chimney	.35			.60		Damper open	(a)	(b)	0	0	50	3	Average.

a Several. b Various lengths. c Upper rear boiler.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
214	8	5 x 3	Near boiler	2	130	[a] 4	12.56	Small combustion chambers. Furnace doors cracked for short time after each firing. Must run with dampers wide open to keep clean stack.
215	11	3.5 x 6	Near stack	0	270	[a] 4.4	14.7	Two boilers equipped with automatic steam jets and air admissions. Stack good with these two boilers in service. Smoke observations include some 10, 20, and 40 per cent black readings. Each furnace equipped with eight $\frac{1}{8}$-inch steam jets.
216	0	.....	.....	0	90	.....	.....	Draft in front of furnace increased about 0.07 inch of water with steam jets on. Automatic steam and air admission; six $\frac{1}{8}$-inch steam jets across front of furnace. Success due to careful operation. Stack smokes from 10 to 20 per cent black for one-half to one minute at each firing. During firing ash-pit doors closed, but opened as soon as furnace doors closed. Some shavings burned. Device in service about two minutes.
217	10	.....	.....	0	100	3 x 3	9	Forced draft through hollow grate bars. Half anthracite and bituminous coal usually burned, to keep smoke down. Some straw refuse burned.
218	32	4.6 x 6	.....	1	235	[a] 6	28.3	U tile on lower row of tubes. Total length of arch over furnace 11.25 feet.
219	22	.....	.....	2	108	[a] 3	7.06	U tile on lower row of tubes to a point within 3 feet of rear water leg. Heating surface figures do not include heating surface of water-tube grates. Fire-brick checker work at rear of lower grate. Two boilers have 14 $\frac{1}{8}$-inch steam jets entering through rear water leg; two boilers have 21 steam jets. Jets not automatic but turned on before firing and left on two to three minutes after firing. Ash-pit doors opened during firing. Two similar stacks. Stacks smoked 20 per cent black for short time at long intervals. Coal wet before firing. Dry coal contains about 15,000 B. t. u. per pound; moisture plus ash in coal as received, 5 per cent.
220	0	0	.....	0	100	[a] 4.25	14.2	U tile on lower row of tubes. Three 3 by 24 inch air openings through front of furnace, also two 10 by 16 inch air openings leading from back of boiler through ash pit to front. Combustion assisted by steam-oil-gas jets. All jets and air admissions automatically operated. Stack on rear of boiler.
221	40	.....	.....	1	255	[a] 4	12.56	U tile on lower row of tubes to a point within 3 feet of rear water leg. Fire occasionally on lower grate, which causes 40 and 60 per cent black smoke from stack for one-half to one minute.
222	12	.....	.....	1	152	[a] 4.5	15.9	U tile on lower row of tubes to a point within 3 feet of rear water leg. 24 $\frac{1}{8}$-inch steam jets pass through stay-bolt holes in rear water leg, not automatic; in use during firing and shortly after. Smoke observations include several 10, 20, and 40 per cent black readings. Automatic regulator on main damper.
223	28	4 x 6	Near stack	1	306	[a] 5.5	23.7	Coal as fired runs moisture 16.5 per cent; ash, 9 per cent; B. t. u. per pound, 10,800.

[a] Diameter.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant.	Breeching. Length from stack to nearest boiler (feet).	Breeching. Size (feet).	Breeching. Place at which measurement was taken.	Breeching. Number of elbows between boilers and stack.	Stack. Height (feet).	Stack. Size (feet).	Stack. Area (square feet).	Remarks.
224	10	4 x 7	Near stack	1	250	[a] 4 x 6	20.56	Furnace doors cracked after each firing. Grates have 55 per cent air space. Plant usually runs with dampers partly closed. Alternate doors fired, spreading method.
225	25	[b] 3	do	2	135	4 x 1.9	7.6	Furnace draft on this type of furnace varies greatly as coal magazine is or is not kept filled. Occasionally, 40 and 60 per cent black smoke at first firing after cleaning fires.
226	7	1 3.5x11 1 3.5x 6		2				Water-tube grates have two rows of tubes staggered. Ash-pit doors kept cracked.
227	20			3	80	[b] 4.2	13.6	Air admission at bridge wall and patent air-admission doors.
228	18	3.5 x 9	Near stack	1	260	[b] 5	19.6	Total length of arch over grates, 9.7 feet. Boilers baffled vertically.
229	15	3 x 6	do	0	200	[b] 4.5	15.9	Boilers baffled horizontally. Steam jets in furnace and brick checkerwork in combustion chamber on boiler with plain grates.
230	17	4 x 6	do	1	150	[b] 5.5	23.7	Staggered water-tube grates. Dampers kept partly closed to carry about 0.5 inch of water in first pass. Brick arches built on bridge wall. Stack occasionally smoked badly when fire was cleaned. Usually run with ash-pit doors closed. Figures for heating surface do not include area of water-tube grates. Considerable 10 per cent black smoke.
231	12			1	279	[b] 5.5	23.8	Fired by spreading method, using alternate doors. Large combustion chambers. Lower row of tubes covered with C tile leaving 5-foot gas passage at rear of boilers. Furnace doors cracked after each firing. Damper regulator.
232	3			0	110	[b] 4	12.56	Figures for heating surface do not include area of water-tube grates. Some rubbish burned.
233	50	3 x 5	Near stack	1	200	4 x 4	16	Large combustion chambers. Draft of 0.80 inch of water in last pass with damper wide open.
234	7			1	225	[b] 4.7	17.1	Detroit water-tube boiler is of Heine type.
235	70	3 x 8	Near stack	1	165	9 x 9	81	Spreading method of firing; fire alternate doors.
236	12	2.5 x 3	do	1	210	[b] 4	12.56	
237	18			1	125	[b] 2.1	3.4	
238	9			1				Automatic steam and air admission device. Large boiler has 27 $\frac{1}{8}$-inch steam jets across front of furnace; small boiler has 14 $\frac{1}{8}$-inch jets. Device automatically opens and closes air-admission openings in furnace doors; is on during firing and one to two minutes later. Very small amount of black smoke for one-half to one minute at each firing.
239	15			1	140	[b] 5	19.6	Coal burned, 3 parts anthracite and 2 parts bituminous. Boilers baffled vertically. Stack smokes 20 per cent black about half the time. Using all bituminous coal makes offensive smoke.
240	10			1	125	3.2 x 3.1	10	Thickest fire in front of furnace. Steam and air admission device runs continuously. Twenty $\frac{1}{64}$-inch jets for superheated steam enter furnace.

[a] Oval.

[b] Diameter.

Plants with return tubular boilers.—The size of the 44 plants having hand-fired furnaces under return tubular boilers varied widely, the smallest being 50 horsepower and the largest 1,000 horsepower. At 45 per cent of these plants run-of-mine, egg, or lump coal was burned. The cost of coal at 31 plants averaged $2.49 per ton, ranging from $1.60 to $4.10. Uniform loads were carried by 34 plants and varied loads by 10. On the average 90 per cent of the rated boiler horsepower (boiler rated on 10 square feet of heating surface per horsepower) was developed on mean heavy load. The furnaces in use at the different plants included 10 types, as follows:

Furnaces used at plants with hand-fired furnaces under return tubular boilers.

	Number of plants.
Dorrance (with Dutch oven)	1
Down-draft	10
McMillan	5
Twin arch	1
Wooley	1
Burke (western, with Dutch oven)	2
Burke (eastern)	1
Plain	21
Cornell economizer	1
Puddington	1

Of these furnaces, 20 had steam-jet attachments. Eleven were equipped with either rocking or dumping grates. At 33 plants either the spreading or the alternate method of firing was used; 5 plants used the coking method.

The average length of travel of the gases to the tube heating surface and the height of the combustion chamber are indicated by the following figures:

Average distance from grates to tube heating surface, 44 plants, 16.6 feet; shortest, 13 feet; longest, 24 feet. Average least distance from grates to tube heating surface, 44 plants, 14.2 feet; shortest, 11 feet; longest, 22 feet. Average vertical distance from grates to shell, 31 plants, 2.3 feet; shortest, 1.5 feet; longest, 5 feet. Average ratio of heating surface to grate surface, 44 plants, 45 to 1; lowest, 26 to 1; highest, 67 to 1.

The draft readings taken at these plants may be summarized as follows:

Average furnace draft, 39 plants, 0.23 inch of water; range, 0.03 to 0.55 inch. Average draft at front tube sheet, 15 plants, 0.41 inch; range, 0.27 to 0.68 inch. Average draft in breeching, 25 plants, 0.51 inch; range, 0.22 to 1.42 inches. Average draft at base of stack, 16 plants, 0.66 inch; range, 0.35 to 1.10 inches.

The following approximate draft averages were deduced from the above: Furnace, 0.25 inch of water; front tube sheet, 0.40 inch; breeching 0.50 inch; base of stack, 0.70 inch. Approximate average drop through the boiler, 0.15 inch.

For convenience the furnaces and devices in use at these plants are discussed in three groups—down-draft furnaces, steam jets, and miscellaneous furnaces and devices.

The essential features of the down-draft furnace are described in the account of hand-fired furnaces under water-tube boilers. Its setting and operation at the 10 return tubular boiler plants where it was found in use are taken up here. All the down-draft furnaces at these plants were set under units of 150 horsepower or less, and none were set in a Dutch oven. Nine of the plants carried a uniform load. At 4 of the plants the coal fired was run-of-mine, nut, or egg. The average cost of coal at 6 of them was $2.68 per ton. At all 10 plants firing was by the spreading method. The kinds of coal burned and the average depth of fire carried were as follows:

TABLE 21.—*Kind of coal and depth of fire at plants with down-draft furnaces under return tubular boilers.*

Kind of coal burned.	Number of plants.	Average depth of fire.	Kind of coal burned.	Number of plants.	Average depth of fire.
		Inches.			*Inches.*
Illinois	1	7	Pennsylvania	2	10
Kentucky	4	8.5	West Virginia	2	11
Ohio	1	9			

The draft, coal consumption, percentage of rated boiler horsepower developed, distance from grates to tube heating surface, and smoke observations show the following averages:

Draft through fire, 0.30 inch of water; range, 0.03 to 0.36 inch.

Coal as received burned per square foot of grate surface per hour, average heavy load, 20 pounds; least, 13.3 pounds; most, 24.4 pounds.

Percentage of rated boiler horsepower developed, average heavy load (boiler rated on 10 square feet of heating surface per horsepower), 96; range, 58 to 157.

Average distance from grates to tube heating surface, 17.1 feet. Least distance from grates to tube heating surface, 14.7 feet.

Smoke emitted, 5.6 per cent black.

The plants visited that had steam jets in the furnaces numbered 20, one of which is included also in the group with down-draft furnaces. At all of them the furnaces were run under boiler units of 150 horsepower or less. The coal burned came from eight States. At 10 plants the size of coal was lump or run-of-mine; the cost ranged from $1.50 to $4.10 per ton, the average being $2.32. Eighteen plants carried fairly uniform loads. Nineteen had furnaces with flat grates. The kinds of coal and the thicknesses of fire carried are shown below.

TABLE 22.—*Kind of coal and depth of fire at plants with steam jets in furnaces under return tubular boilers.*

Kind of coal.	Number of plants.	Average depth of fire.	Kind of coal.	Number of plants.	Average depth of fire.
		Inches.			*Inches.*
Indiana	2	4.5	Tennessee	1	9
Maryland	1	15	West Virginia	5	8.5
Ohio	3	6	Miscellaneous	5	7
Pennsylvania	3	7.3			

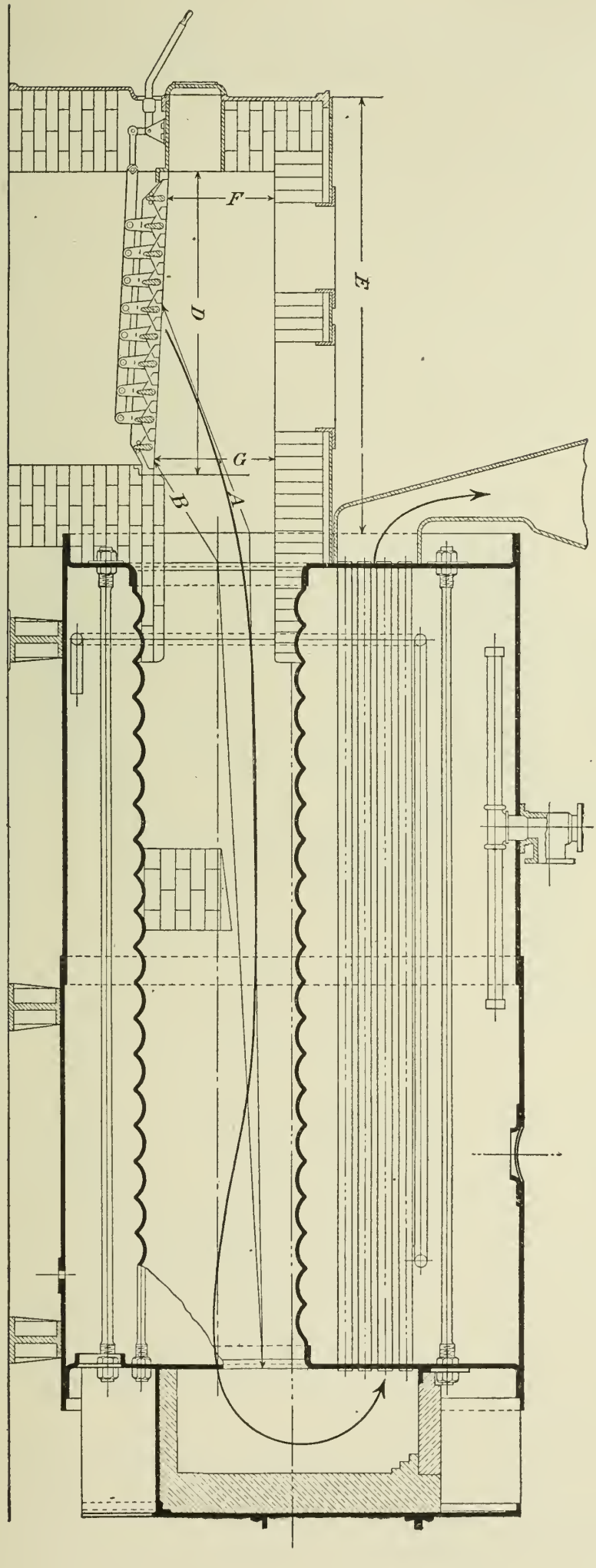


FIGURE 32.—A hand-fired furnace and Scotch marine boiler, elevation.

The draft through the fire, the coal consumption, the furnace setting, and the smoke given off were noted at only 20 plants. The average of the measurements were as follows:

Draft through fire, 0.23 inch of water; range, 0.15 to 0.37 inch.

Coal as received burned per square foot of grate surface per hour, average heavy load, 17.6 pounds; least, 11.2 pounds; most, 25.3 pounds.

Percentage of rated boiler horsepower developed, average heavy load (boiler rated on 10 square feet of heating surface per horsepower), 78; range, 46 to 174.

Average distance from grate to tube heating surface, 15.9 feet. Least distance from grate to tube heating surface, 13.7 feet. Vertical distance, grate to shell, 2.2 feet.

Smoke emitted, 4.2 per cent black.

The miscellaneous group includes all the hand-fired furnaces under return tubular boilers not already described. Three of these furnaces with their distinctive features are briefly described below. Three

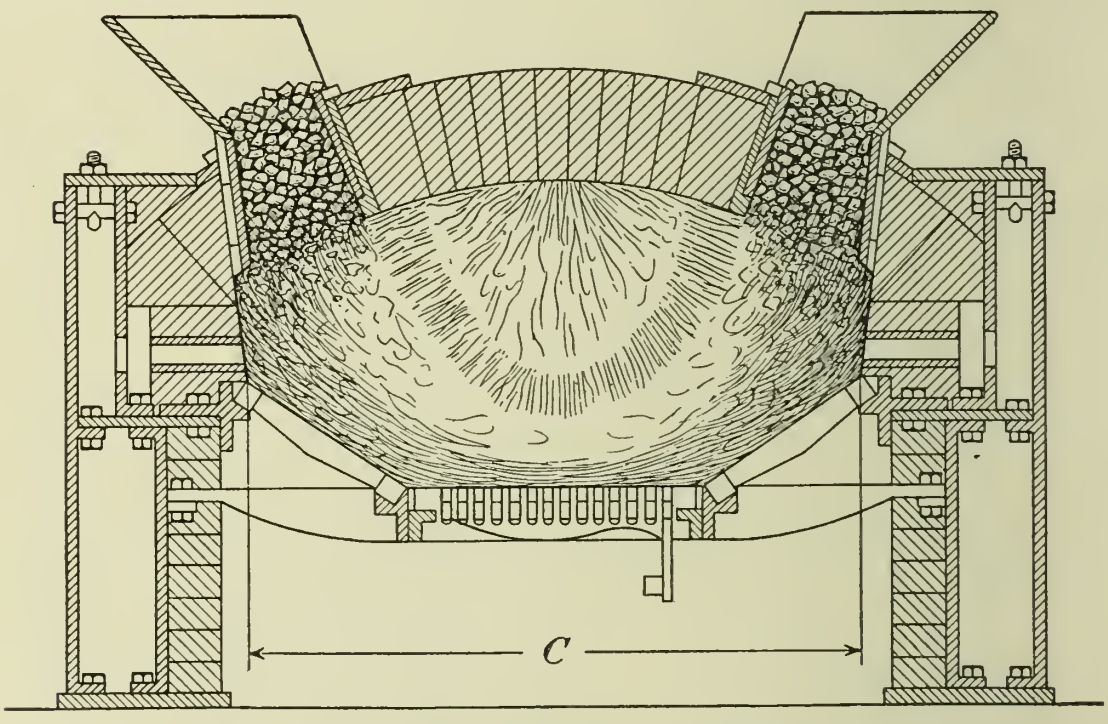


FIGURE 33.—A hand-fired furnace, cross section.

others, including the down-draft, are described in the account of hand-fired furnaces under water-tube boilers (pp. 104–106).

In the first furnace the coal is fired from side hoppers in the furnace wall to a combustion chamber, virtually a Dutch oven, having short sloping grates at the sides with a wide rocking grate between them. The furnace is thus practically a hand-fired side-feed stoker. The Dutch oven construction gives a hot combustion chamber and lengthens the travel of the burning gases. An elevation and a cross section of such a furnace placed in front of a Scotch boiler are presented in figures 32 and 33.

Another furnace having distinctive features intended to insure complete combustion and prevent smoke is shown on page 121. In this pattern (see fig. 34) the furnace gases pass through circular openings in the bridge wall. Immediately beneath these openings

are small rectangular holes by which air that comes through a passage in the bridge enters the furnace. The object of this construction is to admit air in such a way that any unconsumed carbon in the gases

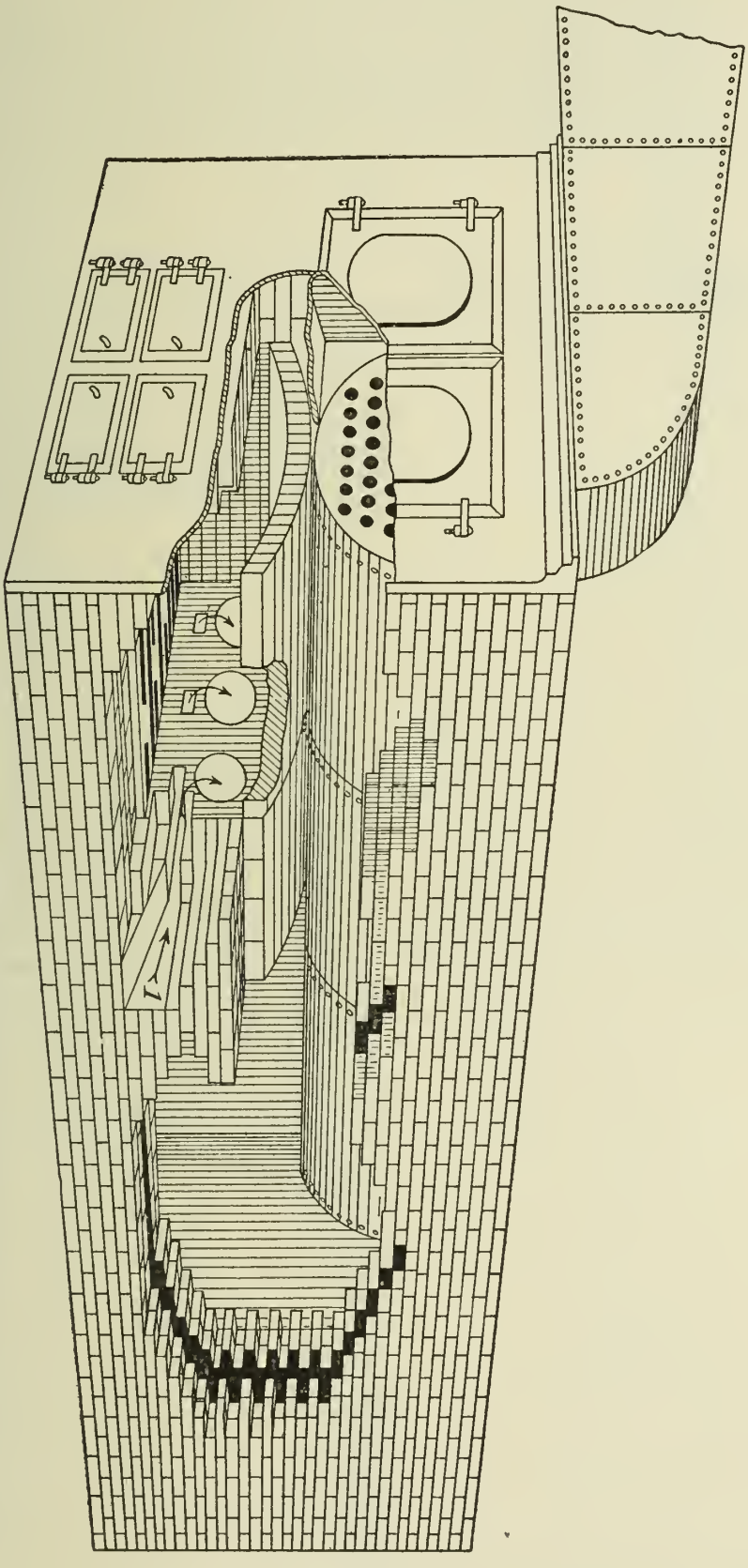


FIGURE 34.—A hand-fired furnace and return tubular boiler. 1, Air admission in bridge wall.

will be brought into contact with the necessary air for burning it without cooling the combustion space.

Another furnace intended to effect smokeless combustion by special fire-brick piers and arches in the combustion space is shown in figures 35–37. Its characteristic features are two furnaces, each with

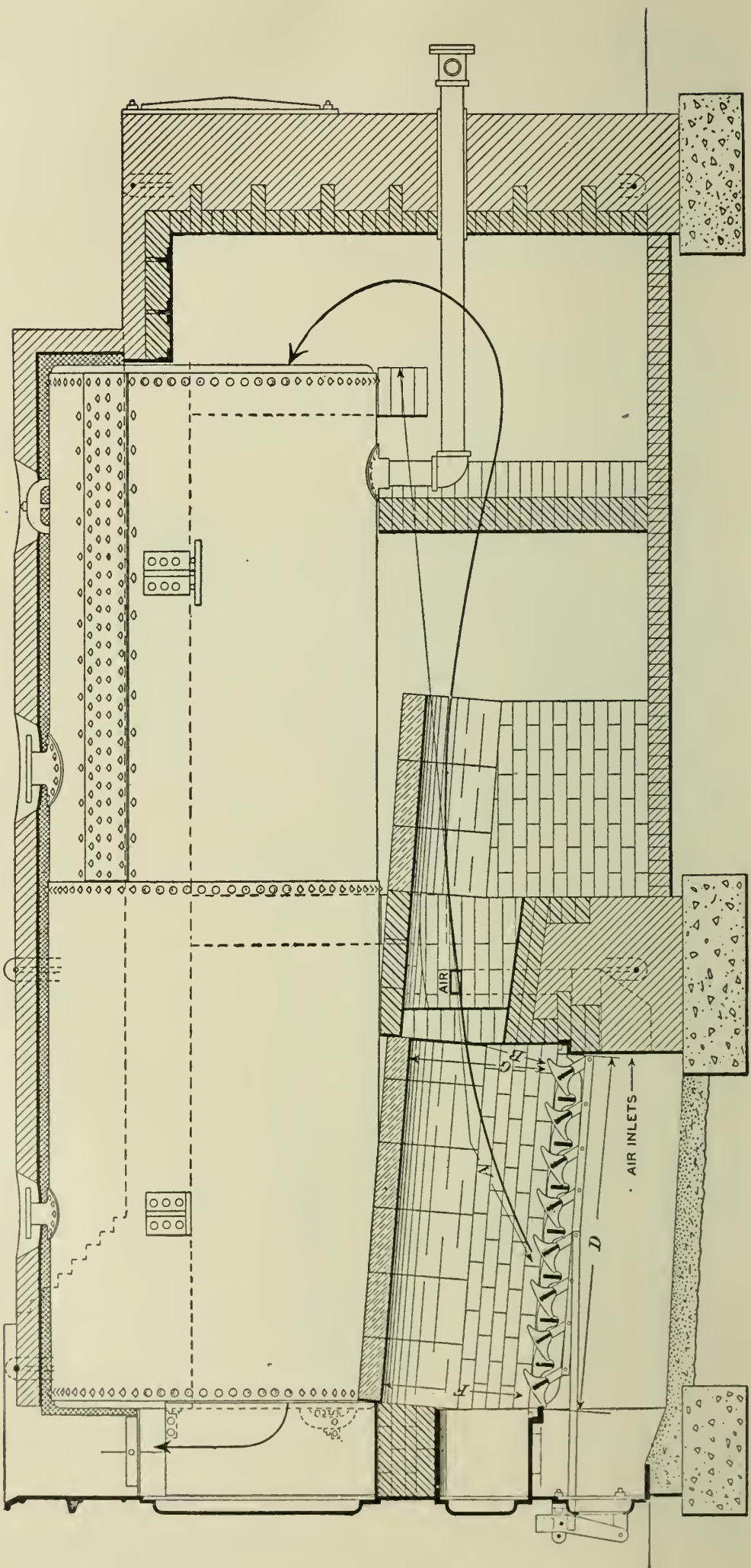


FIGURE 35.—A hand-fired furnace and return tubular boiler, elevation.

an arch extending the entire length of the grate, virtually making small Dutch ovens; a wide-arched passage, in which are openings for

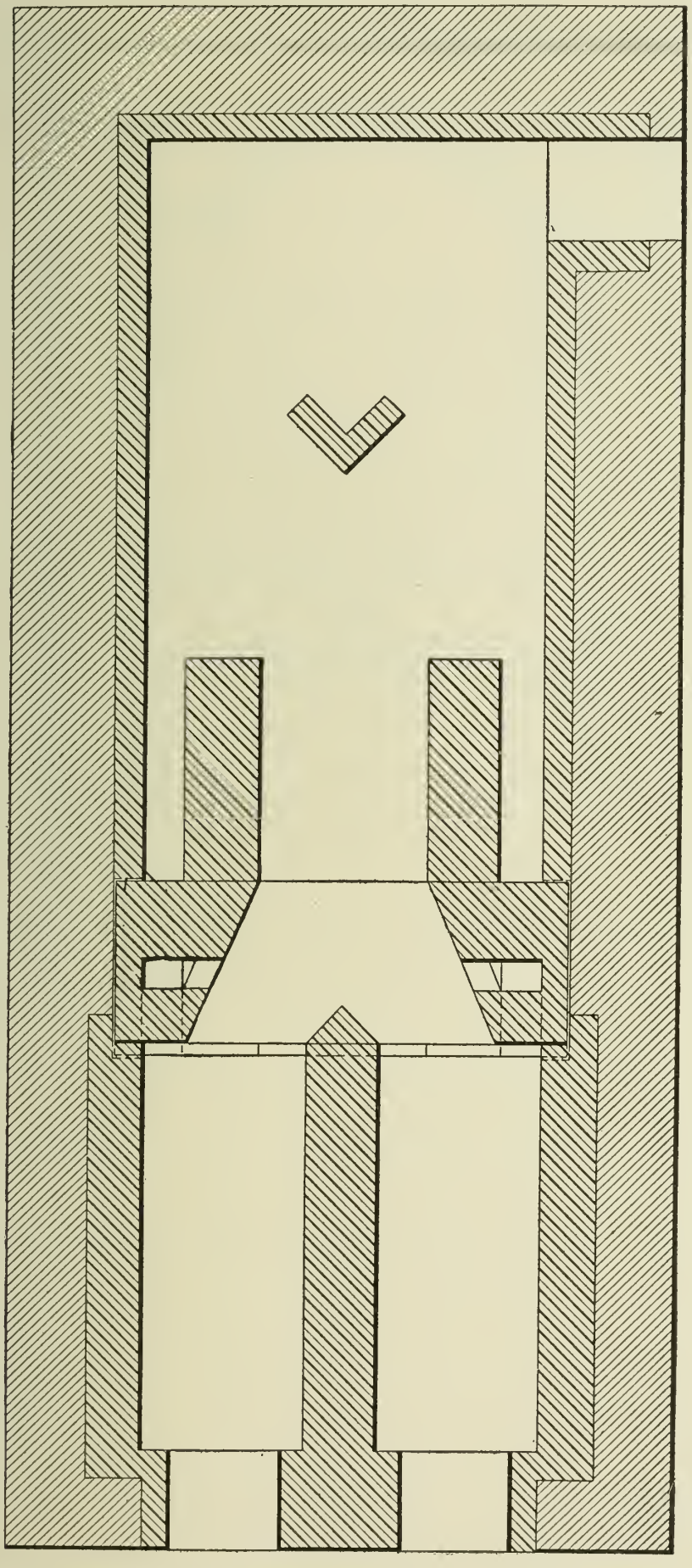


FIGURE 36.—A hand-fired furnace, plan.

air admission, in the wall back of the grates; and another arched passage of greater height back of this. This construction gives a long, irregu-

lar combustion space, evidently intended to permit thorough mixing of gas and air. Figure 35 is an elevation of the furnace as usually installed under a return tubular boiler; figure 36 is a horizontal plan, and figure 37 a cross section.

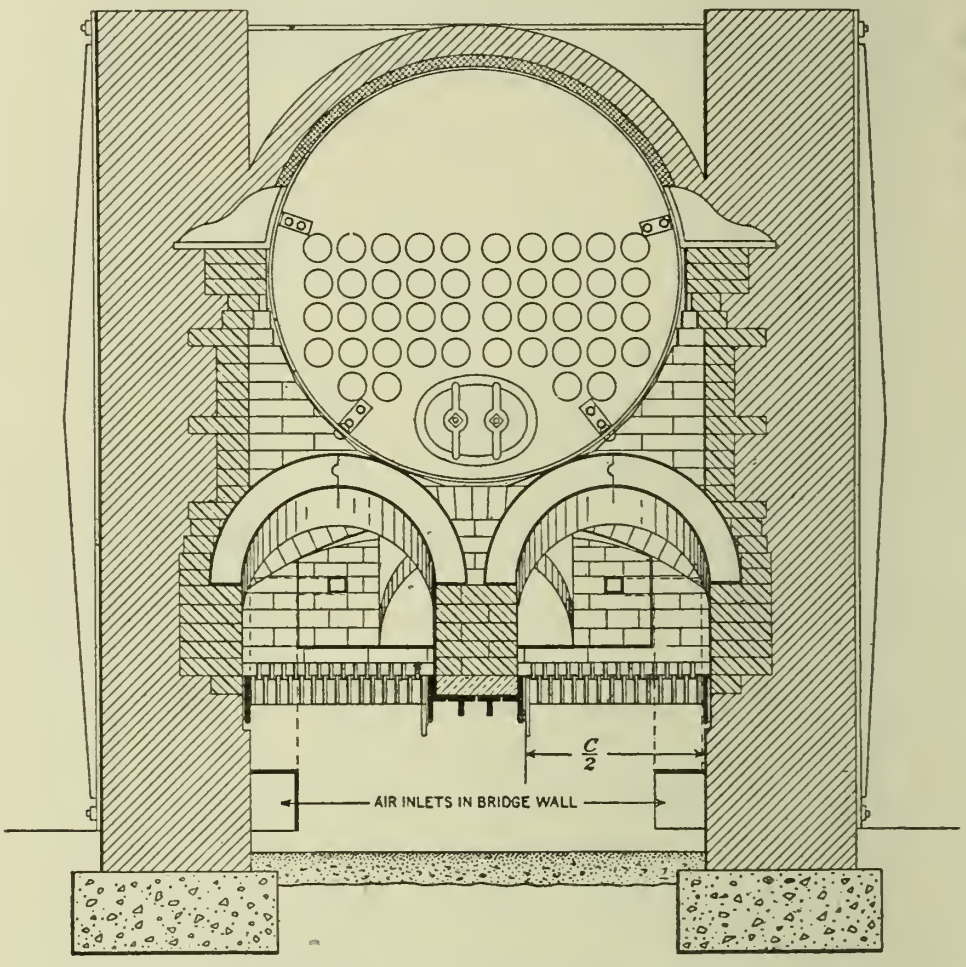


FIGURE 37.—A hand-fired furnace and return tubular boiler, cross section.

The observations on seven different styles of furnaces were averaged to obtain the figures given in the tables below. All of these furnaces were installed under boiler units of 150 horsepower or less. Nine were equipped with either rocking or dumping grates.

The coals burned and the thicknesses of fire carried at the 15 plants classed as miscellaneous were as follows:

TABLE 23.—*Kind of coal and depth of fire at plants with miscellaneous hand-fired furnaces under return tubular boilers.*

Number of plants.	Kind of coal.	Average depth of fire.
		Inches.
8	Illinois	6
2	Indiana	4
1	Pennsylvania	
4	West Virginia	7.7

The average draft through the fire and the average coal consumption were as follows:

TABLE 24.—*Average draft and coal consumption at plants with miscellaneous hand-fired furnaces under return tubular boilers.*

Kind of furnace.	Number of furnaces.	Furnace draft.	Coal as received burned per square foot of grate surface per hour, average heavy load.
		Inch of water.	*Pounds.*
McMillan	5	0.14	22
Dorrance	1	.23	47
Twin arch	1	.27	.....
Wooley	1	.21	16
Burke	2	.11	18
Puddington	1	.12	13.2
Plain	4	.28	14.6

The averages of various items are as follows:

Coal as received burned per square feet of grate per hour, average heavy load, 21.8 pounds.

Percentage rated boiler horsepower developed, averaged heavy load (boiler rated on 10 square feet of heating surface per horsepower), 91.7; lowest, 53; highest, 184.

Average distance from grate to tube heating surface, 16.3 feet. Least distance from grate to tube heating surface, 14.1 feet. Vertical distance, grate to shell or arch, 2.1 feet.

Smoke, 6 per cent black.

Details of the observations at all the plants with hand-fired furnaces under return tubular boilers are given in Table 25.

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers.*

No. of plant.	State.	Device used to facilitate combustion.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
241	Illinois	None	300		Carterville, Ill	3-inch egg	$3.10	
242	Kentucky	do	600		Western Kentucky	Nut and slack		
243	do	do	300		do	Nut, pea, and slack	1.65	
244	do	do	160		do	Pea and slack		
245	do	do	120		do	Nut and slack		
246	Michigan	do	300	Pittsburg No. 8	Ohio	Run-of-mine	2.25	1,070
247	New York	do	500	Rochester; Pittsburg; Reynoldsville.	Pennsylvania	Slack	2.45	3,100
248	Kentucky	do	160		Pittsburg, Pa	Nut and slack		
249	Ohio	Steam jet	400	Pocahontas	West Virginia	Screened lump	3.60	
250	Pennsylvania	None	300		Powellton, W. Va	Run-of-mine	3.02	
251	Ohio	Steam jet	150	Logan block	Indiana	Nut and slack	1.90	
252	Indiana	do	100		do	¾ to 1 inch nut		
253	Maryland	do	130	Georges Creek	Maryland	Run-of-mine		
254	Ohio	do	320	Massillon	Ohio	Slack	1.60	3,200
255	do	do	230	Pittsburg	do	Run-of-mine		
256	do	do	88	do	do	do		
257	New York	do	1,000	Rochester; Pittsburg	Pennsylvania	Lump	$2.65–2.80	12,000
258	Ohio	do	250	Pittsburg	do	Nut and slack	1.90	
259	do	do	170	Jellico	Tennessee	do	2.00	600
260	do	do	500	Kanawha	West Virginia	do	1.70	
261	do	do	450	do	do	do	2.10	
262	Illinois	do	350	Pocahontas	do	Run-of-mine	4.10	
263	Ohio	None	240	do	do	do	2.70	800
264	do	Steam jet	150	Thacker	do	do	2.40	
265	do	None	100	Kanawha	do	Nut and slack	1.90	
266	do	do	90	Pocahontas	do	Slack	2.25	
267	do	do	86	do	do	Run-of-mine		
268	do	Steam jet	411	Various coals		do	1.80–2.10	2,070
269	do	do	300			Nut and slack		
270	do	do	144	Various coals		Run-of-mine	2.60–2.85	600
271	do	do	100			Nut and slack		
272	do	do	87			do	1.80	
273	Illinois	None	250		Carterville, Ill	No. 2	2.85	
274	do	do	250		do	Lump		
275	do	do	166		Illinois	Large lump		
276	do	do	240		Indiana	3 to 6 inch egg	3.15	
277	do	do	116	Block	do		3.90	

278	.....do.....	.....do.....	580	Washed.....	Carterville, Ill.....	No. 4.....	2.90	.....
279	.....do.....	Air admission.....	240	.....do.....	.....do.....	No. 5.....	.....	.....
280	.....do.....	None.....	180	.....do.....	.....do.....	.....do.....	.....	.....
281	.....do.....	.....do.....	160	.....	.....do.....	Run-of-mine.....	.....	.....
282	.....do.....	.....do.....	50	.....	.....do.....	4 to 6 inch egg.....	2.85	.....
283	Ohio.....	.....do.....	500	Pittsburg.....	Pennsylvania.....	¾-inch screenings.....	1.80	4,800
284	New York.....	Steam jet.....	160	Reynoldsville.....	.....do.....	Run-of-mine.....	2.50	700

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers*—Continued.

No. of plant.	Load.			Rating.							
	Requirement.	Nature.	Character.	Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
				Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
241	Power, light, and heat	Uniform	Hospital	24	14	24	7	20	20	84	92	5
242	do	Variable	Manufacturing	24	16	24	7	13.3	12.5	58	45	5
243	do	Uniform	Post-office	24	15	15	6.7	22.1	21.3	112	119	5
244	Power and light	do	Office building	16	3.25	16	2	17.7	14.3	86	102	5
245	do	do	do	19	3.2	19	2.4	20	17.5	114	112	5
246	do	do	Factory	10	3.6	10	3.4	24.4	23.7	112	96	5
247	Power, light, and heat	do	Office building	17	12.5	17	8	19.6	16.1	84	98	4
248	Power and heat	do	Factory	10	5.25	10	5.25	24	24	157	131	5
249	Power, light, and heat	do	Post-office	17	4.3	17	3.5	.....	.....	60	63	4
250	do	do	do	13	10	13	5.5	19.2	16.6	93	128	4
251	do	do	Bakery	18	2.5	24	2.5	11.2	9.8	46	75	5
252	do	do	Laundry	10	3	10	2.5	22.5	20.5	113	120	5
253	Power and heat	do	Offices and factory	12	2	12	1.4	16	13.7	92	111	5
254	Power, light, and heat	do	Shops	9.5	8	9.5	6.5	18.7	16.9	78	105	5
255	do	do	Factory	10	2.4	10	2	16	14.7	70	84	5
256	do	do	do	10	2.4	10	2	16	14.7	81	109	5
257	Heat	Variable	Manufacturing	18	33	6	7	14.5	12	66	84	5
258	Power, light, and heat	do	Brewery	24	8	24	5	22.2	18.1	85	107	5
259	Power and heat	Uniform	Office building	10	2	10	2	22.2	22.2	174	94	5
260	Power, light, and heat	Variable	Brewery	7	6	17	9	25.3	20.5	61	69	5
261	Heat	Uniform	School buildings	12	6	.....	.....	16.7	.....	56	67	5
262	Power, light, and heat	Variable	Office building	19	5	19	3.5	16	14	.....	77	5
263	do	Uniform	do	14	3	14	1.5	17.3	13	89	89	4
264	do	do	Factory	10	3.25	10	2.25	22.5	19.4	99	120	5
265	do	do	.....	10.5	1.5	10.5	1	14.1	11.5	48	57	5
266	Power and heat	do	.....	10	1.5	10	1.2	15	13.5	70	74	4.5
267	do	do	Factory	10.5	1.25	10.5	1	12	10.8	53	56	5
268	do	do	Mill	12	6	12	6	14	14	61	73	5
269	Power, light, and heat	do	Factory	10	8.5	10	8.5	18.9	18.9	91	113	5
270	Power and heat	do	Store building	11	1.8	11	1.8	20.4	20.4	62	91	5

271	Power and light	do	Shops	10	2.5	10	2.5	18.2	18.2	83	100	5
272	Power and heat	do	do	10	1.5	10	.75	16.7	12.6	65	69	5
273	Power, light, and heat	Variable	Factory	9	3	9	2.75	22	21	84	107	5
274	do	do	Manufacturing	10	7	10	6.5	23	22	88	112	5
275	do	Uniform	Factory	8	3	8	2.5	30	28	176	181	5
276	Power and light	do	Manufacturing	10	4	10	3	19	16.5	89	100	5
277	Power and heat	Variable	Factory	10	3.5	8.5	.75	16	12	95	121	5
278	do	Uniform	Office building	12	26	12	.26	47	47	184	150	5
279	do	do	do			10	3		11	70	75	5
280	Power, light, and heat	Variable	Factory	15	6	15	3	16	12	92	133	5
281	Power and heat	Uniform	Office building	18	5	18	3.5	19.4	17	76	100	5
282	do	do	Factory			9	1.5		16.5	106	134	5
283	Power, light, and heat	Variable	Shops	24	13.3	24	13.3	13.2	13.2	56	66	4.5
284	Heat	Uniform	Distilling	5	1.4	5	.6	21.6	18.6	102	156	4.5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers*—Continued.

No. of plant.	Stoking.					Boilers.								
	Method of firing.	Frequency of firing (minutes).	Coal fired at each firing per boiler (pounds).	Thickness of fire (inches).	Frequency of cleaning fire.	Size.	Number installed.	Number used to carry—		Builder's rated horsepower.	Horsepower, boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
								Average heavy load.	Average light load.					
241	Spreading...	20	200	6–8	3 times in 24 hours.....	72″ x 18′, 62 4″ tubes.....	2	2	1	150	138	1,380	0	80
242	.....do.....	Var.	Var.	7–9	.....	72″ x 22′, 26 6″ tubes.....	4	4	2	150	115	1,150	0	100
243	.....do.....	Var.	Var.	8	3 times in 24 hours.....	54″ x 17′, 44 3½″ tubes.....	4	3	2	75	80	800	0	80
244	.....do.....	Var.	Var.	8–10	2 times in 16 hours.....	60″ x 16′, 48 4″ tubes.....	2	1	1	80	95	950	0	100
245	.....do.....	Var.	Var.	8–10	2 times in 19 hours.....	50″ x 16′, 34 3½″ tubes.....	2	1	1	60	59	585	0	90–100
246	.....do.....	8–10	90–110	[a]8–10	2 times in 10 hours.....	66″ x 18′, 58 4″ tubes.....	2	1	1	150	129	1,285	0	110
247	.....	Var.	Var.	[a]10–12	2 times in 24 hours.....	72″ x 16′, 66 4″ tubes.....	4	3	3	125	145	1,450	0	100
248	Spreading...	Var.	Var.	8–10	2 times in 10 hours.....	66″ x 16′, 34 4″ tubes.....	2	2	2	80	67	670	0	90
249	.....do.....	20	270–370	.....	Once in 24 hours.....	60″ x 18′, 54 3½″ tubes.....	4	2	2	100	106	1,060	0	120
250	.....do.....	Var.	120–150	10–12	3 times in 24 hours.....	48″ x 18′, 48 3½″ tubes.....	4	4	3	75	104	1,040	0	105
251	.....do.....	15–17	50–75	6	2 times in 24 hours.....	60″ x 18′, 54 4″ tubes.....	2	1	1	75	120	1,200	0	85
252	.....do.....	5–10	30–50	3	.....	66″ x 16′, 54 4″ tubes.....	1	1	1	100	106	1,060	0	85
253	.....do.....	20–40	80	14–16	Once in 12 hours.....	50″ x 14′, 56 2½″; 50″ x 16′, 56 2½″..	2	1	1	60,70	72,82	720,820	0	80
254	Coking.....	10	60	4–5	2 times in 10 hours.....	60″ x 16′, 47 4″ tubes.....	4	4	4	80	108	1,075	0	90
255	.....	12–18	90–150	6	.....do.....	72″ x 16′, 70 4″ tubes.....	2	1	1	115	138	1,380	0	80
256	.....	12–18	90–150	6	.....do.....	62″ x 16′, 53 4″ tubes.....	1	1	1	88	105	1,050	0	80
257	Spreading...	10–20	150–180	6–8	2 times in 24 hours.....	72″ x 16′, 92 3½″ tubes.....	8	6–8	6	125	159	1,585	0	90
258	.....do.....	Var.	60–80	6–8	3 times in 24 hours.....	72″ x 18′, 70 4″ tubes.....	2	1	1	125	156	1,560	0	95
259	Coking.....	12–20	75–90	8–10	2 times in 10 hours.....	54″ x 20′, 4 8½″ and 2 10″ tubes...	2	1	1	85	46	465	0	85
260	Alternate....	7–10	40–50	4–10	Once in 8 hours.....	72″ x 18′, 64 4″ tubes.....	5	4	4	125	142	1,420	0	85
261	Spreading...	10	75–90	8	Once in 12 hours.....	80 4″ x 18′ tubes.....	3	2	.....	150	178	1,780	0	80
262	.....do.....	Var.	Var.	12–14	.....do.....	.....	3	1	1	80–135	.....	.....	0	95–100
263	Coking.....	Var.	60	Var.	.....	66″ x 18′, 54 4″ tubes.....	2	1	1	120	120	1,200	0	100
264	Spreading...	12–15	60–80	6	Once in 10 hours.....	60″ x 14′, 46 4″ tubes.....	2	2	1	75	91	910	0	75
265	.....do.....	7–12	40–60	6–8	.....do.....	60″ x 18′, 54 4″ tubes.....	1	1	1	100	120	1,200	0	80
266	.....do.....	12–15	60	6	.....do.....	60″ x 16′, 48 4″ tubes.....	1	1	1	90	95	950	0	90
267	.....	15–20	40–60	10	.....do.....	58″ x 16′, 46 4″ tubes.....	1	1	1	86	91	910	0	80
268	.....	15–20	100–140	6	2 times in 12 hours.....	76″ x 18′, 74 4″ tubes.....	3	2	2	137	164	1,640	0	100
269	Spreading...	15–20	40–60	7–8	2 times in 10 hours.....	60″ x 16′, 54 3½″ tubes.....	4	4	4	75	93	930	0	105
270	.....	10–15	50–60	6	1 to 2 times in 11 hours.	60″ x 16′, 72 3″ tubes.....	2	1	1	72	107	1,065	0	75
271	Alternate....	3–8	50–70	5–6	2 times in 10 hours.....	66″ x 18′, 54 4″ tubes.....	1	1	1	87	120	1,200	0	80
272	.....	8–10	40–50	7–8	Once in 10 hours.....	60″ x 16′, 54 3½″ tubes.....	1	1	1	100	92	920	0	80

273	Spreading...	Var.	100–120	4	Once in 9 hours.....	72″ x 18′, 70 4″ tubes.....	2	1	1	125	159	1,590	0	125
274	.....do.....	2–5	80–100	4–10	4 times in 24 hours.....	.....do.....	2	2	2	125	159	1,590	0	115
275	.....do.....	10–12	60–90	6	2 times in 8 hours.....	60″ x 16′, 46 4″ tubes.....	2	1	1	83	85	850	0	80
276	.....do.....	10–15	120–180	3–5	2 times in 10 hours.....	54″ x 16′, 52 3½″ tubes.....	3	2	2	80	90	900	0	70
277	Alternate....	Var.	30–60	4	1 to 2 times in 10 hours.	60″ x 16′, 37 4″ tubes.....	2	2	1	58	74	740	0	80
278	Spreading...	4–5	70–75	5–6	6 times in 24 hours.....	60″ x 18′, 48 3½″; 13 4″ water tubes.	4	4	4	145	118	1,180	0	125
279	Alternate....	12–15	60–70	6–8	.....	60″ x 16′, 44 4″ tubes.....	3	2	2	80	87	870	0	100
280	.....do.....	Var.	30–60	5–6	1 to 2 times in 15 hours.	.....do.....	3	2	2	60	87	870	0	125
281	Coking.....	Var.	Var.	Var.	1 to 2 times in 18 hours.	60″ x 18′, 46 4″ tubes.....	2	2	1	80	102	1,020	0	160
282	.....do.....	Var.	Var.	Var.	Once in 9 hours.....	52″ x 16′, 32 4″ tubes.....	1	1	1	50	63	625	0	110
283	Spreading...	Var.	100–120	.....	.....	72 4″ x 16′ tubes; 144 4″ x 18′ tubes	3	2	2	125,250	142,302	{ 1,420 3,020 }	0	90
284	.....do.....	7–8	45–90	8	Once in 5 hours.....	66″ x 14′, 94 3″ tubes.....	2	1	1	80	122	1,220	0	90

[a] On top grate.

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers*—Continued.

No. of plant.	Furnaces.									
					Dimensions.					
	Number.	Kind of furnace.	Kind of grate.	Grate area per boiler (square feet).[a]	Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance at front of furnace from grates to coking arch or heating surface (F).
					Average (A).	Minimum (B).				
241	2	Hawley	Water-tube and flat	30	17	14.5	6	5	0	.....
242	4	.....do	.....do	25	22	20	6	4.2	0	.....
243	4	.....do	.....do	20.2	17	15	4.5	4.5	0	.....
244	2	.....do	.....do	23	16	13.5	5	4.6	0	.....
245	2	.....do	.....do	16.7	16	14	4.2	4	0	.....
246	2	Down-draft	.....do	29.5	17	14	4.5	6.5	0	4
247	4	Hawley	.....do	25	15	12	5	5	0	5
248	2	.....do	.....do	22.4	16	14	5.6	4	0	.....
249	4	.....do	.....do	.....	17	14.5	.....	.....	0	.....
250	4	.....do	.....do	20	17.5	15.5	4	5	0	.....
251	2	Plain	Flat	25	17	14.5	5	5	0	2.2
252	1	.....do	Rocking	26.7	16	13.5	5.1	5.25	0	2.2
253	2	.....do	Flat	21, 23	[b] 13.5, 15.5	[b] 11, 12.5	4.2	[b] 5, 5.5	0	2
254	4	Burke	Flat and dumping	22.5	15	13	4.5	5	0	2.5
255	2	Plain	Flat	30	16.5	14	6	5	0	2.4
256	1	.....do	.....do	30	16.5	14	6	5	0	2.4
257	8	.....do	.....do	36	15	12	6	6	0	2.5
258	2	.....do	.....do	30	16.5	14	6	5	0	1.7
259	2	.....do	.....do	18	19	17	4.5	4	0	.....
260	5	.....do	.....do	27	17	15	6	4.5	0	2.1
261	3	.....do	.....do	30	17	15	6	5	0	2.5
262	3	.....do	.....do	25, 33	.....	.....	[b] 5, 6	[b] 5, 5.5	0	2.5
263	2	.....do	.....do	24.75	17.5	15.5	5.5	4.5	0	2.3
264	2	.....do	.....do	20	13	11	5	4	0	2.5
265	1	.....do	.....do	20.25	17	15	4.5	4.5	0	2.2
266	1	.....do	.....do	20	15.5	13.5	5	4	0	2.3
267	1	.....do	.....do	20	15	13	5	4	0	1.75
268	3	.....do	.....do	36	16.5	14	6	6	0	2.5
269	4	.....do	.....do	22.5	15	13	5	4.5	0	1.7

270	2	.....do.....	.....do.....	16	15	13	4	4	0	2.5
271	1	.....do.....	.....do.....	27.5	16.5	14	5.5	5	0	.....
272	1	.....do.....	.....do.....	18	15	13	4.5	4	0	1.75
273	2	McMillan smokeless.....	Rocking.....	30	17.5	15	6	5	0	1.5
274	2	.....do.....	Shaking.....	30	17.5	14.3	6	5	0	1.8
275	2	.....do.....	Rocking.....	25	15.5	13	5	5	0	1.7
276	3	.....do.....	Shaking.....	21	15.5	13	4.5	4.7	0	1.7
277	2	.....do.....	Flat.....	22.5	17.5	15.5	5	4.5	0	1.6
278	4	Dorrance.....	Shaking.....	23	24	22	5.1	4.5	7.7	2.25
279	3	Twin arch.....	Rocking.....	28	15	12	2.3	6	0	2
280	3	Woolley.....	Shaking.....	25	16	13.5	5	5	0	2.1
281	2	Burke.....	Rocking.....	19	20	18	4.75	4	5	.....
282	1	.....do.....	.....do.....	20.25	21	19	5.1	4	5	.....
283	3	Puddington.....	Flat.....	42	[c] 3.5, 14	[c] 3, 11	6	7	0	[c] 2.5, 4
284	1	Plain with Cornell economizer.....	.....do.....	25	13	11	5.5	4.7	0	2

[a] In down-draft furnaces, area of upper grate only.

[b] First dimension applies to small boiler.

[c] First dimension applies to tubular boiler.

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers*—Continued.

No. of plant.	Kind.	Draft. Readings (inches of water). Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.	Conditions under which readings were taken.	Smoke records. Number of observations.	Total length of observations (minutes).	Average for one hour (minutes). 100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.	Average percentage of black smoke from observations.	Load during observations.
241	Chimney..	0.25	.....	.....	.....	.....	Damper open, ash-pit doors cracked.	1	50	1	2	35	11.7	Average.
242	....do.....	0.20–.39	.....	.....	0.53	.....	Dampers and ash-pit doors open.	1	60	0	0	48	3.3	Light.
243	....do.....	.22	.....	.....	.40	0.46	Dampers open, ash-pit doors closed.	1	110	0	1	36	6.4	Average.
244	....do.....	.55	.....	.....	.57	.....	Ash-pit doors closed, damper open.	2	94	0	0	58	.7	Light.
245	....do.....	.32	.....	.....	.47	.....	Damper open, ash-pit doors closed.	1	60	0	1.5	58	1.5	Do.
246	....do.....	.03	.....	0.60	.....	.60	Lower furnace doors cracked....	1	60	0	4	54	5	Average.
247	....do.....	.24–.34	.....	.42–.55	.....	.67	.....	1	60	0	0	58	.7	Light.
248	....do.....	.21–.51	.....	.....	.55	.....	Damper open, ash-pit doors cracked.	2	77	0	0	55	3	Average.
249	....do.....	.30–.35	.....	.45–.50	.85	.....	Dampers open.....	4	295	0	0	0	21	Heavy.
250	....do.....	.22–.44	.....	.....	.60	.65	.....do.....	1	75	0	0	50	3	Do.
251	....do.....	.19	.....	.....	.28	.....	Damper open, thick fire.....	(a)	(b)	0	0	.....	.....	Do.
252	....do.....	.20	.....	.27	.31	.....	Damper open.....	2	45	0	0	53	5.5	Light.
253	....do.....	.25	.....	.....	.48	.....	.....do.....	1	.....	0	0	.....	.....	Heavy.
254	....do.....	.18–.27	.....	.36–.38	.....	.45	.....	1	60	0	0	58	.7	
255	....do.....	.30	.....	.35	.....	.....	.....	1	60	0	0	57	1.3	Average.
256	....do.....	.23	.....	.30	.....	.....	.....	1	60	0	0	57	1.3	
257	....do	.14–.18	.....	.25–.30	.....	.....	.....	1	60	0	0	42	7.9	Light.
258	....do	.28–.30	.....	.....	.40	.....	Damper open.....	(a)	(b)	0	0	.....	.....	Heavy.
259	....do.....	.....	.....	.....	.35	.70	.....do.....	(a)	(b)	0	0	.....	.....	Average.
260	....do.....	.....	.....	.40	0.35–.60	.65	Dampers open.....	(a)	(b)	0	0	.....	.....	Heavy.
261	....do.....	.....	.....	.....	.....	0.75–1	Damper open.....	(a)	(b)	0	0	.....	.....	Do.
262	....do.....	.....	.....	.....	.....	.....	.....	1	60	0	0	59	.1	Light.
263	....do.....	.....	.....	.....	.....	.85	Damper open, thin fire.....	(a)	(b)	0.	0	.....	.....	Heavy.
264	....do.....	.15	.....	.....	.45	.....	Damper open, ash-pit doors two-thirds closed.	(a)	(b)	0	0	.....	.....	Do.
265	....do.....	.37	.....	.....	.60	.....	Damper open.....	(a)	(b)	0	0	.....	.....	Do.
266	....do.....	.30	.....	.....	.50	.....	.....do	(a)	(b)	0	0	.....	.....	Do.
267	....do.....	.18	.....	.....	.43	.....	.....do.....	(a)	(b)	0	0	.....	.....	Do.

268	....do.....	.13–.27	.....	.28–.29	.....	.70	.....	1	60	0	3	45	9.3	Average.
269	....do.....	.20	.....	.....	.42–.45	.....	Dampers open.....	(a)	(b)	0	0	.....	.....	Do.
270	....do.....	.27–.32	.....	.45	.....	.....	.....	1	60	0	0	55	2.3	Do.
271	....do.....	.15	.....	.....	.....	.35	Damper open, ash-pit doors partly closed.	(a)	(b)	0	0	50	5.6	Do.
272	....do.....	.17–.20	.....	.....	.40	.52	Damper open.....	(a)	(b)	0	.....	.....	.....	Heavy.
273	....do.....	.17	.....	.35	.....	.....	Dampers open.....	2	65	.....	.....	.....	.....	Average.
274	....do.....	.12–.17	.....	.....	.....	.62	Damper and ash-pit doors open.	1	54	0	2	33	10.7	Do.
275	....do.....	.20–.22	.....	.....	.44	.....	Damper open.....	1	60	2	2	39	9.6	Light.
276	....do.....	.11	.....	.....	.47–.56	.....	Damper and ash-pit doors open.	1	60	0	3.5	38	9.8	Average.
277	....do.....	.06	.....	.....	.22	.....	Damper open, banked fire.....	1	60	0	5	35	11.6	Light.
278	....do.....	.17–.28	c0.33–.48	.....	1.34–1.50	.....	Dampers and ash-pit doors open.	2	395	0	0	57,54	2.5,.7	Heavy.
279	....do.....	.27	.....	.....	.....	1.10	Damper open.....	3	127	0	6	50	3.8	
280	....do.....	.20–.22	.....	.44–.46	.64	.....	.....do.....	1	60	0	3.5	48	6.3	Light.
281	....do.....	.14	.....	.68	.....	.82	.....do.....	1	60	0	0	57	2.5	Heavy.
282	....do.....	.08	.....	.....	.45	.....	.....do.....	1	60	0	.5	54	3.4	Light.
283	....do.....	.10–.13	.32–.34	.....	.....	.....	.....	1	30	0	0	(d)	5	Heavy.
284	....do.....	.24–.33	.....	.35	.....	.47	Device in use during readings...	1	60	0	0	.....	.....	

a Several. b Various lengths. c Combustion chamber. d 56 water tube, 46 tubular.

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
241	27	3 x 4	Near stack	0	100	4.5 x 6	27	Heating surface in water-tube grates not figured in heating surface. Water-tube grate, single row of tubes. Considerable, 10 to 20 per cent, black smoke from stack.
242	5			0	100	*a* 5	19.6	Large combustion chambers. Stack occasionally not as good as recorded observations.
243	55	2.2 x 4	Near stack	3	105	3 x 4	12	Coal as fired runs 12,500 B. t. u.; ash, 15 per cent; moisture, 5 per cent. Figures for heating surface do not include heating surface in water-tube grates. Stack occasionally not as good as recorded observations. Automatic regulator on main damper.
244	30			2	95	*a* 1.8	2.64	Heating-surface figures do not include heating surface in water-tube grates. Large combustion chambers.
245	20			1	130			Large combustion chambers.
246	0	0		0	105	*a* 4	12.56	Five-inch fire on secondary grates. Heating-surface figures do not include heating surface in water-tube grates. Stack on front of boiler. Stack smokes 60 to 80 per cent black about one-half minute at every firing.
247	10			0	112	3 x 4	12	Three- to 4-inch fire on secondary grates. Boilers arched over the top for gas passage.
248	22			1	115	*a* 4	12.56	Large combustion chambers.
249	10			3	152	*a* 4.5	15.9	Twenty $\frac{1}{8}$-inch steam jets at base of bridge wall in combustion chamber; not automatic; turned on before firing and left on for three to four minutes after. Considerable, 10, 20, and 40 per cent black smoke from stack. Automatic regulator on main damper.
250	65			1		*a* 4	12.56	Coal breaks up easily, and nearly all slack as fired. Heating-surface figures do not include heating surface in water-tube grate. Boilers arched over top for gas passage. Eight- to 10-inch fire on secondary grate.
251	17			2	90	*a* 3	7.06	Steam jets and air admission, $7\frac{1}{8}$-inch jets across front of furnace. Device in service about two and one-half minutes at each firing. Stack smokes at each firing 40 per cent black or less for one to two minutes. 9 by 4 inch air opening in each dead plate.
252	9			0	50	2.7x2.7	5.65	Six $\frac{1}{8}$-inch steam jets enter through front of furnace, automatic with opening of furnace doors. Average firing produces about 40 to 50 per cent black smoke, for one-half to three-fourths of a minute.
253	8			0				Boilers arched over top for gas passages. 16 to 17 $\frac{1}{8}$-inch steam jets in combustion chamber at base of bridge wall; not automatic; turned on before firing and allowed to run from three to four minutes.
254	4			4	100	*a* 4	12.56	Two coking ovens per boiler; also four $\frac{1}{16}$-inch steam jets in bridge wall which draw heated air into furnace. Air taken in over the fire and through ash-pit doors. Boilers arched over the top for gas passage.
255	21			1	85	*a* 3.75	11.1	Arch sprung across combustion chamber just at rear of boiler. Twelve $\frac{3}{32}$-inch steam jets across front of each furnace, automatic with two 6 by 10 inch air inlets in each door. Smoke preventer in operation five or six minutes at each firing.

256	7			1	85	*a* 3.75	11.1	Arch sprung under rear of boiler makes gas passage longer and aids in mixing and distributing gases. Smoke preventer in operation five or six minutes at each firing. Nine $\frac{3}{32}$-inch steam jets across front of furnace, automatic with two 6 by 10 inch air inlets in each furnace door.
257	15			1	85	*a* 4	12.56	Two steam jets, each with six $\frac{3}{16}$-inch openings, not automatic, enter front of each furnace. Patent air-admission door. Three similar stacks. Considerable, 20 per cent, black smoke. Success due to careful operation and firing.
258	3			0				Automatic steam and air admission device. Seven $\frac{1}{8}$-inch steam jets across front of furnace. At average firing stack smokes 30 per cent black and less for one and one-half to two minutes. Device in service about two and one-half minutes at each firing.
259	24			2	125	*a* 2.5	7.06	Four $\frac{5}{64}$-inch steam jets across front of furnace; not automatic. At average firing stack smokes 20 per cent black and less for one to one and one-half minutes.
260	3			1	125	*a* 6	28.3	Four $\frac{1}{8}$-inch steam jets; not automatic. Two arches, one in front and one behind bridge wall. Smokes about 40 per cent black and less at each firing for one and one-half to two minutes. Fire carried about 2 feet back from furnace doors. Two 2 by 4 inch air openings in each coking plate; also a $1\frac{1}{2}$ by 24 inch opening always open for air admission. Steam jets turned on before firing and kept on from three to five minutes. Jets entering furnace pass through air-admission pipes.
261	53			1	140	*a* 5	19.6	Automatic steam and air admission device. Eight $\frac{1}{8}$-inch steam jets across front of furnace. During average firing stack smokes from 20 to 40 per cent black for one-half to one minute. Air openings 1 by 6 inches in each dead plate.
262	6			1	160	*a* 5.5	23.8	Large combustion chambers. Four $\frac{1}{16}$-inch steam jets across front of furnace; not automatic; jets used during and shortly after firing. Smoke kept down by careful operation.
263	7			1	165	3 x 3	9	Retorts in bridge wall for gases to pass through. Less than 20 per cent black smoke for about one minute when firing. About 50 per cent air space in grate. Furnace not very hot. Lumps of coal 8 to 10 inches in diameter fired.
264	20			1	75	2.3 x 2.3	5.4	Automatic steam and air admission device. Seven $\frac{1}{8}$-inch steam jets across front of furnace. At each firing stack smokes 40 per cent black and less for three to four minutes. 5 by 12 inch air opening in each coking plate. Lumps of coal 8 inches in diameter fired.
265	9			1				Smoke observations include some 10, 20, and 40 per cent black readings.
266	0	0		0	80			Coal cokes badly, and fire requires frequent poking. Stack rests on boiler. At each firing stack smokes 60 per cent black and less for about one minute.
267	9			1				Lumps of coal up to 6 inches in diameter fired. Smoke observations include some 10, 20, and 40 per cent black readings.
268	12			1	110	*a* 4	12.56	Automatic steam jets and air admission; eight $\frac{1}{8}$-inch steam jets across front of furnace. also an 8 by 20 inch air opening in each dead plate.
269	14			1				Automatic steam jets and air admission. Six $\frac{1}{16}$-inch steam jets across front of furnace. Four similar stacks. During average firing stacks smoke from 60 to 20 per cent black for three-fourths to one minute.
270	42			3	125	*a* 3	7.06	Six $\frac{1}{16}$-inch steam jets across front of furnace. One steam jet at either side of furnace, not automatic; also a patent furnace door for air admission, not automatic. Success due to careful firing and operation.
271	15			0	75	2.5x2.5	6.25	Steam jets and air admission device run continuously. Twenty $\frac{1}{64}$-inch steam jets enter furnace.
272	23			2	68	3.5x3.5	12.25	Automatic steam jets and air admission. At each firing stack smokes about one minute. 40 to 60 per cent black and one to one and one-half minutes 20 to 40 per cent black. Seven $\frac{1}{16}$-inch steam jets and two $\frac{1}{8}$-inch steam jets across front of furnace. Device in service from three to five minutes.

a Diameter.

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
273	6	3.5 x 3.5	Near stack	1	97	3.5x3.5	12.25	One mixing pier on bridge wall, 18 inches wide. Furnace doors perforated but plant usually run with one furnace door three-fourths open. Water in ash pit to cool grates. Success due to careful operation, light firing, and cracking of furnace doors after firing.
274	34	3.5 x 4.5	do	1	105			Mixing pier on bridge wall 18 by 24 inches. Perforated furnace doors.
275	20	3 x 3	do	1	100			Large combustion chambers. Mixing pier on bridge wall. Some refuse burned. Patent furnace doors for air admission.
276	3			1	120	3 x 3	9	Large combustion chambers. Three retorts in bridge wall. Considerable wood burned. Perforated furnace doors for air admission. Stack smokes from 10 to 60 per cent black.
277	25			1	60	[a] 5	19.6	Fire thick, practically banked, on light load. One mixing pier on bridge wall. Perforated furnace doors.
278				1, 2	235	[a] 5.3 5.5x4.5	22.3 24.7	Coal as fired runs about 12,000 B. t. u. per pound. Always one furnace door on each boiler open when running.
279	12			1	235	[b] 5x3	7.8	Two 4 by 6 inch openings in rear of bridge wall for air admission. Ash pit kept filled with water.
280	12			1	110	6 x 6	36	Side grates not included in grate area. Side grates for air admission; mixing structures in combustion chamber.
281	23			1	190	[a] 3.5	9.6	Large combustion chambers. Some of the coal very fine and cakes, so magazines are not kept filled; probably necessary to break up fire to keep magazines full. With magazines not full considerable air enters.
282	22	2.5 x 2.8	Near stack	2	65	2.2x2.2	4.8	Large combustion chambers.
283	0	0		0	85, 125	[a] 3, [a] 3.5	7.07, 9.6	One large and one small boiler always carry load. Automatic steam and air admission in furnace; mixing structure in combustion chamber. Three stacks resting on boilers. Automatic steam jets, in use at each firing for three to four minutes.
284	30			1	80	[a] 3.75	11.1	Forty $\frac{1}{2}$-inch openings across front of furnace for superheated steam. Stack smokes 10 per cent black for one-half minute at each firing.

[a] Diameter.

[b] Oval.

SUMMARY.

The remarks in Tables 20 and 25 show that in many of the hand-fired furnaces an attempt was made to lengthen the travel of the gases from the grates to the heating surface. The design of some furnaces showed recognition of the value of mixing the air and the gases, and arches, retorts, piers, or steam jets were used to accomplish this end. Where steam jets were used they were usually installed so as to be automatically thrown in and out of service.

The regulation of air admission was accomplished at some plants by cracking the furnace door after firing, at others by taking air through the dead plates or through openings in patent furnace doors. These openings in the dead plates and furnace doors were usually automatic with the opening of the doors and were slowly closed by a weight and dash pot. This arrangement allowed the most air to enter the furnace at the required time.

All hand-fired furnaces which will burn coal without objectionable smoke approach the theory of the mechanical stoker, but owing to the variability introduced by the personal element, they can not under average conditions give as good results.

SMOKE OBSERVATIONS AT GEOLOGICAL SURVEY FUEL-TESTING PLANTS.

TESTS AT NORFOLK, VA.

The boiler plant at Norfolk was equipped with two furnaces—one fired by hand, the other by a mechanical stoker. The hand-fired furnace had plain grates and mixing structures in the combustion chamber. The mechanical stoker was of the underfeed type. Figure 38 shows the elevation and plan of the boiler setting; figure 39 gives a cross section of the setting and the plan of the bridge wall. All of the coal used in the tests was of the same general grade; it coked and was low in volatile matter. An expert fireman was employed. Each test lasted about eight hours.

HAND-FIRED TESTS.

The hand-fired furnace was set under a Heine boiler which had C tile on the lowest row of tubes. The tile-roof furnace thus formed, in combination with the mixing structures, proved to be a good design for burning coal low in volatile matter. With this boiler six tests were made, a number too small to permit the drawing of any very definite conclusions. The plant developed from 78 to 155 per cent of the builder's rated capacity and made very little smoke; on no test did the smoke average 10 per cent black. The boiler efficiency on the six tests averaged 66.90 per cent, varying from 65 to 69. The dry coal burned per square foot of grate per hour ranged from 13.7 to 27.6 pounds.

The tests showed that the percentage of volatile matter in the combustible is an element always to be considered. Even with

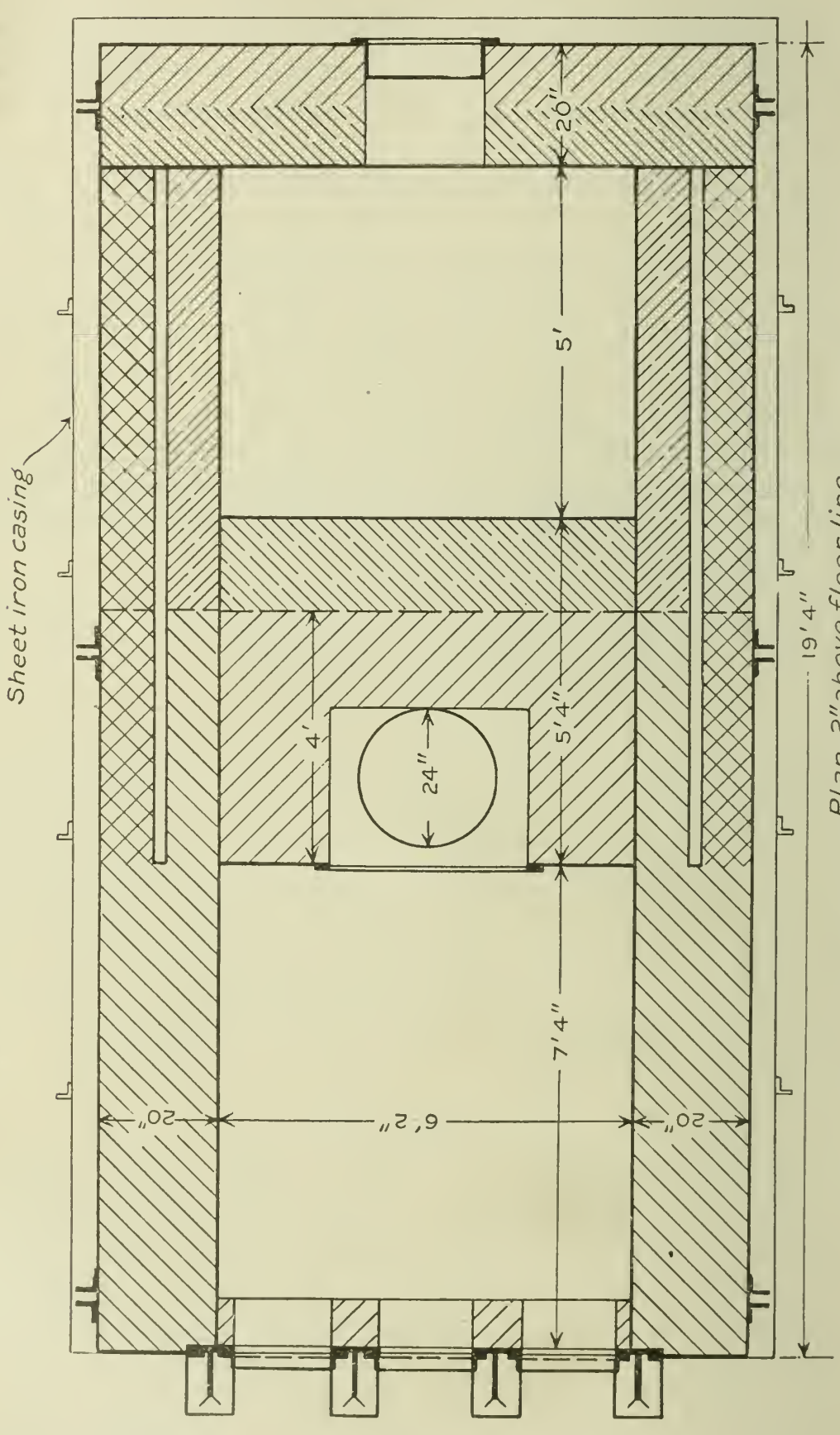
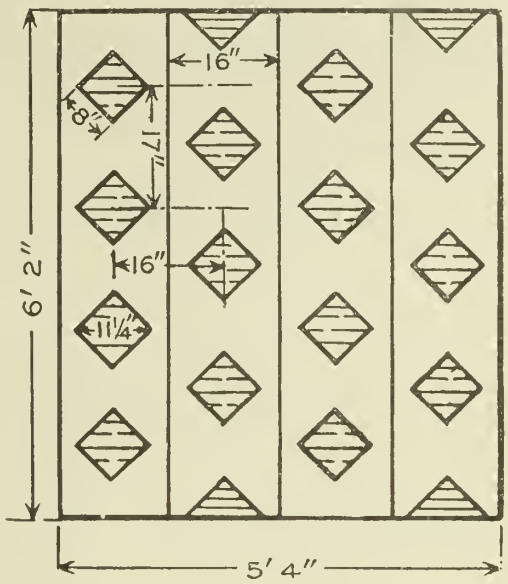


FIGURE 33.—Elevation and plan of setting of hand-fired Heine boiler at Norfolk, Va.

small variations the percentage of efficiency follows it closely. High volatile matter gives low efficiency, and vice versa.

The highest efficiency was obtained when the plant was run at low capacity. The most carbon monoxide was found in the flue gas and the greatest unaccounted for loss in the heat balance when the plant was run at high capacity, showing that forcing the furnace decreased the efficiency. The smoke determinations do not seem to harmonize with some of the expected relations; but these readings vary a great deal and are not as reliable as some of the other items. In determining efficiency it must not be overlooked that incomplete combustion is not the only varying element. In all six tests the percentage of black smoke was so small that a variation in



Plan of bridge wall

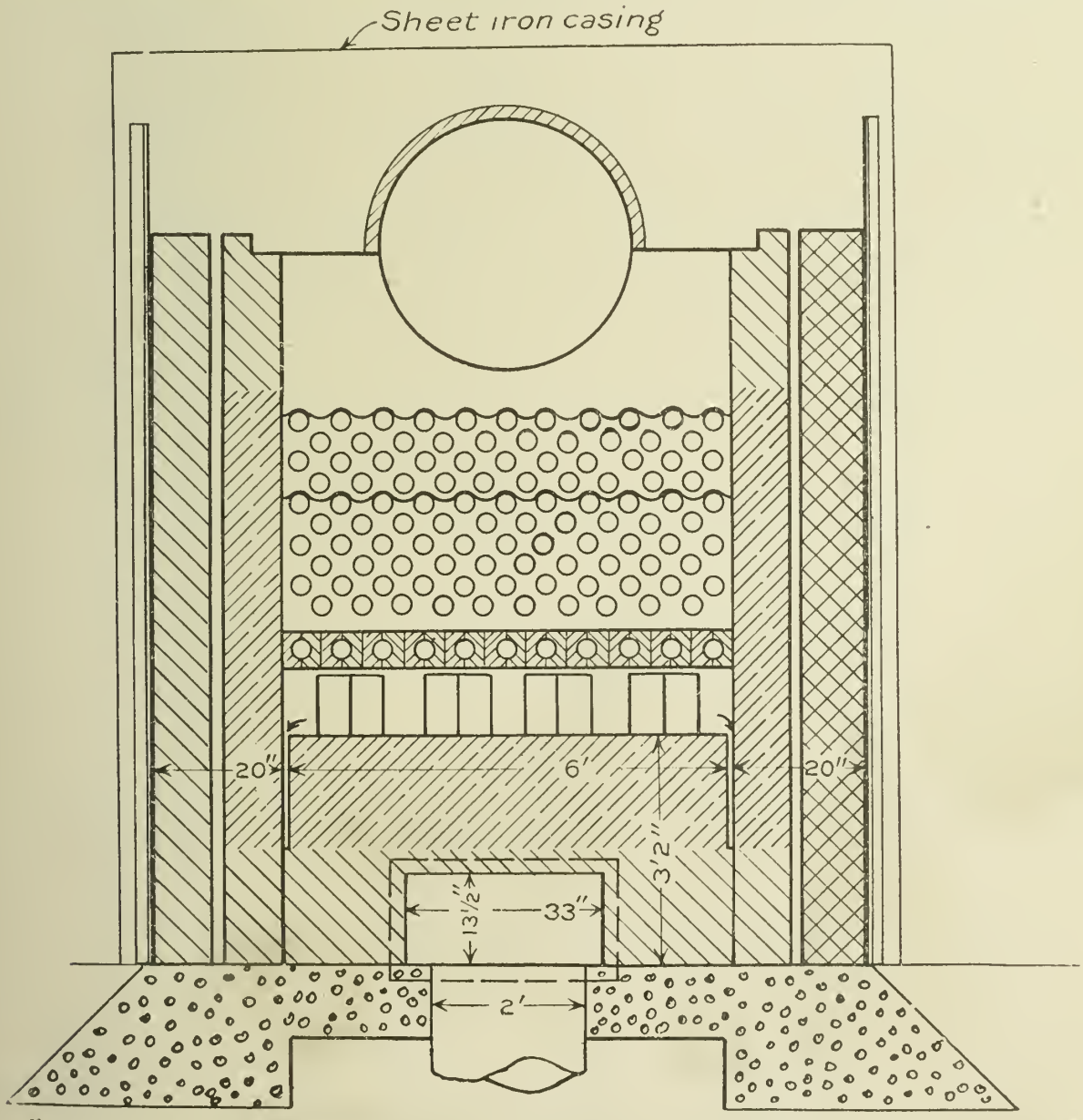


FIGURE 39.—Cross section of setting of hand-fired Heine boiler at Norfolk, Va., and plan of bridge wall.

temperature could make the smoke determination and the efficiency noncomparable.

Five tables compiled from the data collected during these tests are given below:

TABLE 26.—*Results of hand-fired smoke tests at Norfolk, Va., on basis of boiler efficiency 72*.*

Efficiency 72* (per cent).[a]	Black smoke (per cent).	Combustion-chamber temperature (°F.).	Volatile matter in combustible (per (cent).	Percentage of builder's rated capacity developed.	CO_2 in flue gas (per cent).
64.91	5.5	2,192	20.36	81.0	6.26
64.93	6.2	2,523	19.31	129.5	.....
66.29	5.6	2,442	19.97	154.8	6.73
67.69	8.2	2,678	17.05	102.2	10.93
68.61	8.6	2,264	16.78	78.3	6.96
68.94	8.4	2,016	16.48	80.6	7.04

[a] Efficiency 72* figured from pounds of combustible ascending from the grate, the ash being determined by analysis of the dry coal.

TABLE 27.—*Results of hand-fired smoke tests at Norfolk, Va., on basis of unaccounted for loss in heat balance.*

Unaccounted for (per cent).	CO_2 in flue gas (per cent).	CO in flue gas (per cent).	Percentage of builder's rated capacity developed.	Loss up stack (per cent).	Black smoke (per cent).
5.02	6.73	0	154.8	23.67	5.6
9.42	7.04	0	80.6	18.14	8.4
9.86	6.26	0	81.0	21.51	5.5
11.02	6.96	.06	78.3	16.43	8.6
13.05	10.93	.09	102.2	14.97	8.2

TABLE 28.—*Results of hand-fired smoke tests at Norfolk, Va., on basis of black smoke.*

Black smoke (per cent).	Combustion-chamber temperature (° F.).	Efficiency 72* (per cent).	Volatile matter in combustible (per cent).	Percentage of builder's rated capacity developed.	CO_2 in flue gas (per cent).
5.5	2,192	64.91	20.36	81.0	6.26
5.6	2,442	66.29	19.97	154.8	6.73
6.2	2,523	64.93	19.31	129.5	.....
8.2	2,678	67.69	17.05	102.2	10.93
8.4	2,016	68.94	16.48	80.6	7.04
8.6	2,264	68.61	16.78	78.3	6.96

TABLE 29.—*Results of hand-fired smoke tests at Norfolk, Va., on basis of combustion-chamber temperature.*

Combustion-chamber temperature (° F.).	Efficiency 72* (per cent).	Percentage of builder's rated capacity developed.	Black smoke (per cent).
2,016	68.94	80.6	8.4
2,192	64.91	81.0	5.5
2,264	68.61	78.3	8.6
2,442	66.29	154.8	5.6
2,523	64.93	129.5	6.2
2,678	67.69	102.2	8.2

TABLE 30.—*Results of hand-fired smoke tests at Norfolk, Va., on basis of CO_2 in flue gas.*

CO_2 in flue gas (per cent).	Combustion-chamber temperature (° F.).	Efficiency 72* (per cent).	Volatile matter in combustible (per cent).	Black smoke (per cent).	Pounds of air per pound of combustible.
6.26	2,192	64.91	20.36	5.5	34.96
6.73	2,442	66.29	19.97	5.6	32.74
6.96	2,264	68.61	16.78	8.6	31.81
7.04	2,016	68.94	16.48	8.4	31.74
10.93	2,678	67.69	17.05	8.2	20.64

TESTS WITH MECHANICAL STOKER.

At the same plant 23 tests were made with an underfeed stoker under a Heine boiler. The boiler was baffled so as to form a tile-roofed furnace. It contained 2,031 square feet of heating surface and was rated by its builders at 210 horsepower. The boiler efficiency 72* averaged 67.4 per cent and varied from 61.83 to 73.71 per cent. On arranging the test data and calculated results on the basis of efficiency it was shown that there was no general relation between efficiency and any other item. The combustion on all the tests was nearly perfect, the highest average percentage of black smoke being 5.3. The percentage of rated capacity developed ranged from 53.8 to 175. The average percentage of CO_2 in the flue gases ranged from 5.97 to 11.61. The average combustion-chamber temperatures varied between 1,792° and 2,575° F.

The results of these tests are shown in Table 31 on the basis of black smoke observed, and in Table 32 on the basis of dry coal burned per hour.

TABLE 31.—*Results of smoke tests with underfeed stoker at Norfolk, Va., on basis of black smoke.*

Black smoke (per cent).	CO_2 in flue gas (per cent.)	CO in flue gas (per cent).	Percentage of builder's rated capacity developed.	Combustion-chamber temperature (° F.).
0	6.81	0	54.8	1,792
0	9.01	0	74.8	1,978
0	7.38	0	70.7	2,014
.5	7.88	0	75.8	2,192
.8	7.99	0	57.7	1,920
.8	8.58	0	93.0	2,070
.9	10.00	0	94.9	2,196
1.0	5.97	0	83.1	2,136
1.1	7.66	0	58.9	2,053
1.1	9.58	0	73.5	2,133
1.2	9.58	0	71.4	2,003
1.3	7.55	0	131.5	2,381
1.8	8.76	0	124.7	2,311
1.9	7.62	0	56.4	2,016
2.0	9.61	.03	106.3	2,205
2.2	8.58	.06	105.0	2,192
2.2	10.74	.04	126.0	2,352
2.3	6.85	.10	124.0	2,296
3.4	9.49	.04	91.9	2,336
3.9	10.74	.03	115.3	2,298
3.9	11.61	.11	175.0	2,575
5.3	11.25	.16	127.9	2,347

TABLE 32.—*Results of smoke tests with underfeed stoker at Norfolk, Va., on basis of dry coal burned per hour.*

Dry coal burned per hour (pounds).	Black smoke (per cent).	Efficiency 72* (per cent).	CO_2 in flue gas (per cent).	CO in flue gas (per cent).	Combustion-chamber temperature (° F.).
376	0	69.58	6.81	0	1,792
396	.08	67.60	7.99	0	1,920
414	1.1	66.52	7.66	0	2,053
421	1.9	65.04	7.62	0	2,016
469	1.1	73.71	9.58	0	2,133
482	1.2	68.62	9.58	0	2,003
489	0	68.44	7.38	0	2,014
497	0	70.01	9.01	0	1,978
531	.5	66.62	7.88	0	2,192
570	1.0	68.47	5.97	0	2,136
636	.9	69.41	10.00	0	2,196
682	.8	63.44	8.58	0	2,070
711	2.2	69.62	8.58	.06	2,192
735	3.4	68.98	9.49	.04	2,336
813	2.0	63.91	9.61	.06	2,205
872	2.2	68.00	10.74	.04	2,352
879	3.9	63.90	10.74	.03	2,298
887	2.9	65.97	10.76	0	.....
894	1.3	69.13	7.55	0	2,381
901	2.3	64.51	6.85	.10	2,296
921	5.3	68.59	11.25	.16	2,347
938	1.8	61.83	8.76	0	2,311
1,209	3.9	68.11	11.61	.11	2,575

It will be noted that, as has been pointed out by Breckenridge,[a] a high percentage of CO_2 is not necessarily an indication of high economy. When the air supply is reduced, the furnace temperature, CO_2, CO, and smoke are all increased after a certain capacity is reached.

Theoretically, better results should be obtained with only enough air to supply the necessary oxygen, but in practice with most equipments there is a limit to the capacity of the furnace for burning the volatile matter in the coal, and the limited supply of air results in incomplete combustion, which more than offsets the effects of high furnace temperature and high CO_2.

The following general relations have been deduced from a study of the data collected: When the percentage of black smoke was the highest, the CO_2 and the CO in the flue gases, the capacity, and the combustion-chamber temperature were highest, and vice versa; there was no definite relation with boiler efficiency. This may be taken to mean that a stoker properly installed can be operated under wide variations in capacity with different conditions of operation, and yet run smokelessly and with high efficiency.

TESTS AT ST. LOUIS, MO.

The plant at St. Louis had two hand-fired Heine boilers; one furnace had a flat grate, the other a rocking grate. Either natural draft or forced draft supplied by a fan could be used. The bottom row of

[a] Breckenridge, L. P., A study of four hundred steaming tests: Bull. U. S. Geol. Survey No. 325, 1907.

water tubes in each boiler was incased in tile, forming tile-roof furnaces. In most of the tests these furnaces contained some sort of structure to mix the air and the gases from the fire, and thus hasten combustion. An expert fireman working under the direction of a competent engineer was employed in all tests.

The following tables and deductions are compiled from tests made at this plant and supplement the observations in the field and at Norfolk, as they throw light on several points which have heretofore been little considered or at least not fully determined. All the tables have a bearing on the problem of smoke prevention and they are presented because they may be of assistance in its solution.

Table 33 shows the results of six tests made to determine the best method of hand firing a high-volatile Illinois coal, nut size, using natural draft. The proximate analysis of the coal as fired showed the following: Volatile matter, about 36 per cent; ash, about 10 per cent; moisture, about 13 per cent; British thermal units average, 10,948.

Four different methods of firing were used—ribbon (firing alternately in narrow strips across the full length of the grate), coking, alternate, and spreading. In every test a reasonably thin fire was carried, from 2 to 3 inches of incandescent fuel above the clinker. When firing by the spreading method three shovelfuls of coal were thrown on the back of the grate and two on the front. When firing by the ribbon method the fire doors were kept cracked.

The average of tests 500 and 504 was taken as representative of the alternate method of firing. On test 500 the furnace doors were closed tightly after each firing; on test 504 they were kept cracked. This cracking of the furnace doors, while it caused a slight reduction in smoke compared with test 500, proved to be wasteful because the combustion space was not constructed so as to make the excess air of value in hastening combustion. A compromise method, cracking the doors for a short time after firing and then closing them, ought to give as good if not better results for alternate firing than those shown in the table.

The ribbon method of firing, where the coal was fired most frequently with the smallest amount per firing, gave the highest efficiency and practically no smoke. The usual spreading method of firing gave the lowest efficiency and caused the most smoke. The results with the alternate and the coking methods showed that one was about as good as the other.

TABLE 33.—*Results of comparative tests on Illinois coal to determine best method of firing.*

No. of test.	Kind of draft.	Method of firing.	Efficiency 72*.	Black smoke.	Average interval between firings.	Coal per firing.	Percentage of rated capacity developed.	Observation of stack for one hour.
			Per ct.	*Per ct.*	*Minutes.*	*Pounds.*		
503	Natural...	Ribbon.....	62.22	5.0	2.3	50	106.7	Twenty per cent black smoke 15 minutes; clean 45 minutes.
502	.....do.....	Coking.....	60.49	15.0	7.4	140	95.0	Twenty per cent black smoke 48 minutes, very seldom as high as 40 per cent; clean 12 minutes.
a 500	....do.....	Alternate...	59.87	15.8	3.5	70	106.5	One hundred per cent black smoke 4½ minutes, 80 per cent 4½ minutes, 60 per cent 3 minutes, 40 per cent 1½ minutes, 20 per cent 6 minutes; clean 41 minutes.
a 504								Forty per cent black smoke 6 minutes, 20 per cent 24 minutes; clean 30 minutes.
501	.....do.....	Spreading ..	57.56	32.0	9.3	170	92.7	One hundred per cent black smoke 15 minutes, 80 per cent 1½ minutes, 60 per cent 1½ minutes, 40 per cent 4½ minutes, 20 per cent 6 minutes; clean 32 minutes.
505	Forced....	Alternate...	60.20	14.9	3.4	85	131.6	Sixty per cent black smoke 4½ minutes, 40 per cent 3 minutes, 20 per cent 24 minutes; clean 29 minutes.

a Average.

Table 34 is instructive because it shows the possibility of utilizing high-ash coals. Although the grate area was too small to obtain the rated capacity of the boiler, steam was produced at a reasonable efficiency. Owing to the distribution of the combustible in the coal as fired and to the low rate of the combustion, no smoke was produced.

TABLE 34.—*Results of tests on high-ash coals.*

No. of test.	Field designation of fuel.	Kind of draft.	Clinker in refuse.	Volatile matter in combustible.	Ash in coal.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry flue gas.	Moisture in coal.
			Per ct.	*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
451	Argentina No. 1.....	Forced..	60	39.32	50.16	34.20	51.01	0	0.15	6.94
458	Argentina No. 1 (washed).	....do....	48	34.41	31.33	52.90	57.82	0	.26	16.48
479	Washery refuse.....	....do....	69	36.35	41.82	72.60	57.08	0	.40	10.83
	Average.....	.....	59	36.69	41.10	53.23	55.30	0	.27	11.42

Tables 35 and 36 were compiled to show the effect of size of coal on efficiency developed and smoke produced. All coal used in the tests summarized in Table 35 had an average diameter of over 1 inch; that used in the tests summarized in Table 36 had an average diameter of less than one-half inch.

TABLE 35.—*Results of tests with coals having an average diameter of over 1 inch.*

Field designation of coal.	No. of test.	Average diameter of coal	Efficiency. 72*.	Black smoke.	Percentage of rated capacity developed.	Pounds of air per pound of combustible.
		Inches.	*Per cent.*	*Per cent.*		
Alabama:						
No. 2 B	383	1.12	65.83	30.0	93.9	23.73
Do	382					
Illinois:						
No. 19 B	175					
Do	205					
No. 22 A	324					
Do	325					
No. 24 B	337					
No. 25	338					
Do	339	1.97	65.13	19.7	97.8	20.33
No. 26	341					
Do	342					
No. 27	353					
No. 28 C	452					
No. 29 B	461					
No. 34 B	509					
Indiana:						
No. 13	432					
No. 14	431					
Do	430	1.27	66.82	12.0	90.3	20.55
No. 15	428					
No. 17	441					
Kentucky:						
No. 5	276					
No. 6	271	1.14	67.27	19.4	96.2	19.74
Do	270					
Ohio:						
No. 4	254					
No. 5	186					
No. 7	269					
No. 8	287					
No. 9 A	249	1.29	66.20	25.1	99.6	19.26
No. 10	469					
No. 11	474					
Do	475					
Pennsylvania:						
No. 5	286					
No. 5 (washed)	194	1.29	66.90	23.8	99.6	19.67
Do	195					
No. 19	498					
Tennessee:						
No. 1	344					
Do	345					
Do	346					
No. 2	369					
No. 3	350	1.58	66.26	24.1	106.6	21.38
Do	349					
No. 4	356					
No. 7 A	372					
Virginia:						
No. 2	247	1.03	66.90	41.4	95.9	17.63
No. 2 (washed)	260					
West Virginia:						
No. 16 A	304					
No. 21 (washed)	274	1.20	68.59	12.8	109.3	19.89
No. 22 B	438					
No. 23 A	439					
Wyoming:						
No. 2 B	196					
Do	213	1.22	61.72	18.6	83 6	20.61
No. 3	212					
Do	211					

TABLE 36.—*Results of tests with coals having an average diameter of less than one-half inch.*

Field designation of coal.	No. of test.	Average diameter.	Efficiency 72*.	Black smoke.	Percentage of rated capacity developed.	Pounds of air per pound of combustible.
		Inches.	*Per cent.*	*Per cent.*		
Alabama:						
No. 4	377					
No. 5	478	0.39	67.25	8.5	91.4	26.53
Do	480					
Arkansas:						
No. 7 A	293					
Do	294	.37	67.20	0	79.3	26.50
Illinois: [a]						
No. 19 A	160					
Do	161					
Do	163	.36	66.40	13.5	90.3	19.27
Do	170					
Do	171					
Indiana: No. 4 [b]	166	.45	66.38	2.0	74.7	23.64
Indian Territory: No. 9	449	.35	65.20	3.0	97.0	23.77
Maryland: No. 1	222	.34	65.28	8.2	80.1	21.45
New Mexico: No. 4 B	395	.39	65.12	18.0	100.6	25.13
Pennsylvania:						
No. 8	242					
Do	239					
Do	238					
Do	237					
Do	236	.36	66.87	3.6	87.5	23.14
No. 15	472					
Do	473					
No. 16	471					
No. 17	506					
Tennessee: No. 9 A	365	.44	64.24	12.0	98.8	24.93
Virginia: No. 6	507	.46	63.39	3.0	101.8	25.84
West Virginia:						
No. 13	180					
No. 17	225					
No. 19	289					
Do	285	.46	68.93	9.8	86.9	22.18
No. 22 A	447					
Do	446					

[a] Test 129 omitted, no smoke having been recorded.
[b] Tests 164 and 176 omitted, clinker having caused trouble.

These two tables show that both large and small sizes of coal from the same State were burned. All tests in which owing to some factor, such as trouble with clinker, the air distribution was not due to the size of the coal were omitted in compiling results. Table 37 gives a comparison of the average results of Tables 35 and 36. It shows that with either large or small coal about the same efficiency resulted. Unfortunately for direct comparison the large coals burned more readily and produced higher capacities than the small in nearly every test; also with the large coal less air was used per pound of combustible. Nearly all the small coals burned with little smoke, while all the larger sizes caused considerable black smoke.

TABLE 37.—*Comparison of average results of tests with small and large sizes of coal.*

Number of tests.	Average diameter.	Efficiency 72*.	Black smoke.	Percentage of rated capacity developed.	Pounds of air per pound of combustible.
	Inches.	*Per cent.*	*Per cent.*		
31	0.39	66.88	7.4	88.6	23.07
53	1.46	65.97	21.3	98.3	20.28

Table 38 is of especial interest, for it shows that lignites, peat, and subbituminous coals with 47 to 67 per cent of volatile matter in the combustible can be hand-fired with the production of only a small amount of smoke. The average indicates that the boiler was run up to the rating at an efficiency of about 60 per cent. The smoke averaged less than 10 per cent black.

TABLE 38.—*Results of tests on lignites, peat, and subbituminous coals.*

Field designation of fuel.	No. of test.	Kind of draft.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry flue gases.	Unaccounted for in heat balance.
			Per ct.	*Per ct.*		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Arkansas No. 10	340	Forced	0	53.77	104.0	60.25	0	0.34	.....
Florida No. 1 (briquets)	386	Natural	29	67.24	113.2	58.19	13	.10	9.34
Montana No. 2	470	...do	0	42.07	113.2	68.11	18	.02	6.00
Montana No. 3	477	...do	58	41.76	115.2	65.78	12.5	.07	8.65
North Dakota No. 3	206	Forced	57	56.71	90.7	57.46	0	0	13.32
Texas No. 4	291	...do	0	54.88	89.1	61.37	0	0	6.88
	298	...do	0	55.14	104.1	52.01	12	0	17.59
	303	...do	28	53.07	96.4	53.05	14	.24	14.84
Washington No. 1 B	290	Natural	0	47.99	81.8	65.04	10	.07	8.89
Wyoming No. 6	400	...do	14	47.19	93.1	57.84	3.5	.04	16.22
Average	.....	.....	18.6	51.98	100.1	59.91	8.3	.08	11.30

Tables 39 to 41 supplement one another. Table 39 gives the average results of tests which showed a high percentage of black smoke; Table 40 gives the coals used in these tests and contains some remarks explanatory of the high percentage of smoke in particular tests; and Table 41 gives the results of tests with coal which made little smoke.

A comparison of Tables 40 and 41 shows that the coals which smoked the worst clinkered the most. The smoky coals also had higher percentages of volatile matter in the combustible, were burned at higher capacities, and gave a lower efficiency than the less smoky coals.

Among the comparatively smokeless tests were two on Utah coal and two on Missouri coal in which, for some unaccountable reason, the coals burned with a low efficiency; with these four tests omitted from the average, the low-smoke tests gave an average efficiency of 66.93 per cent, with a percentage of builder's rated capacity developed of 96.6. The high-smoke tests gave an average efficiency of 64.32 per cent, with a percentage of rated capacity developed of 99.2, showing a good percentage in efficiency in favor of the low-smoke tests. There are many briquet tests included in Table 41, and Table 42 shows that as a general rule the briquets made very little smoke. The other tests which gave low percentage of smoke were made with coals low in volatile matter, or slow burning, or else some means besides the automatic operation of the air-admission doors was employed to supply more air.

TABLE 39.—*Results of tests showing 35 per cent or over of black smoke.*

[Tests using natural draft, 34; forced draft, 5.]

	Average.	Range.
Clinker in refuse.....per cent..	49.9	0 to 67
Volatile matter in combustible.....do....	42.88	36.38 to 51.58
Percentage of rated capacity developed.....	99.2	84.4 to 129.9
Efficiency 72*.....per cent..	64.32	56.64 to 69.36
Black smoke.....do....	41.8	35.0 to 54.8
CO in dry chimney gases.....do....	.28	.07 to .73
Unaccounted for in heat balance.....do....	12.55	5.71 to 19.03

TABLE 40.—*Coal giving over 35 per cent black smoke.*

Field designation of fuel.	No. of test.	Remarks.
Illinois:		
No. 7 E	516	Forced draft; automatic air admission not operated.
No. 13 (washed)	144	Automatic air admission operated.
No. 15 (washed)	152	Clinker removed with difficulty; automatic air admission operated.
No. 16	150	Automatic air admission operated.
Indiana:		
No. 5	153	Heavy clinker formed on grate; automatic air admission operated.
No. 6 (washed)	159	Automatic air admission operated.
No. 7 A	158	Do.
No. 8 (washed)	184	Do.
No. 9 A	168	Do.
Nos. 9 A and 9 B (briquets)	334	Do.
No. 10	167	Do.
No. 10 (washed)	177	Do.
Kansas: No. 6 (washed)	323	Do.
Missouri: No. 7 (washed)	332	Forced draft; clinker solid; automatic air admission not operated; maximum-capacity test.
Ohio:		
No. 3	203	Automatic air admission operated.
No. 4	202	Clinker adhered to grate; automatic air admission operated.
No. 4 (washed)	220	Automatic air admission operated; coal caked badly.
Do	219	Clinker fused into grate; automatic air admission operated.
No. 5	190	Automatic air admission operated.
Do	186	Do.
No. 7	269	Clinker adhered to grate; automatic air admission operated.
No. 9 A	246	Automatic air admission operated.
No. 9 B (washed)	241	Do.
No. 9 B (washed and dried)	243	Do.
Pennsylvania:		
No. 5 (washed)	195	
No. 6	217	Do.
Tennessee: No. 2	367	Maximum-capacity test; doors cracked after each firing; combustion wall down during test.
Virginia:		
No. 2	251	Automatic air admission operated.
Do	247	Do.
No. 2 (washed)	260	Do.
No. 4	240	Clinker fused into grate; automatic air admission operated.
West Virginia:		
No. 15	216	Forced draft; automatic air admission operated.
Do	215	Automatic air admission operated.
No. 21 (washed)	267	Do.
Wyoming: No. 2 B	213	Forced draft; maximum-capacity test; automatic air admission not operated.

TABLE 41.—*Results of tests showing less than 6 per cent black smoke.*

Field designation of fuel.	No. of test.	Clinker in refuse.	Volatile matter in combustible.	Ash in dry coal.	Moisture in coal as received.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Remarks.
Alabama:		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
No. 2 B (briquets)	410										Some of these coals caked in fire; they burned with both long and short flame; automatic air admission operated only on test 378. Furnace doors cracked after each firing on test 390.
No. 3	390										
No. 4	378	39	35.13	16.18	4.22	93.0	66.88	2.3	0.10	.....	
No. 4 (briquets)	413										
No. 5	478, 480										
Arkansas:											
No. 7 A	293, 294										
No. 8	297	45	15.16	10.98	5.21	85.2	66.17	0	.15	8.18	Coals slow burning; automatic air admission not operated.
No. 8 (washed)	308, 309										
Georgia: No. 1	481	65	21.21	17.77	3.11	111.8	70.31	2.5	.08	6.19	Coal burned freely; automatic air admission not operated.
Illinois:											
No. 6 B (briquets)	313										
No. 9 C (briquets)	492, 497										
No. 11 C (briquets)	312										
No. 12 B (briquets)	463										
No. 19 C	420, 423										
No. 19 D	424, 425										
No. 20	292										
No. 21	316										
No. 21 (briquets)	318										
No. 23 A (washed)	317	49	42.01	13.41	11.94	92.6	64.58	1.7	.06	8.57	Coals free burning; automatic air admission operated only on the coal tests. On test 503 furnace doors were cracked continuously; on tests 420, 424, and 425 the furnace doors were cracked for a short interval after each firing.
No. 25	338, 339										
No. 26	342										
No. 28 A (washed; briquets)	459										
No. 28 B (briquets)	457										
No. 29 B (washed; briquets)	465										
No. 30 (washed; briquets)	511										
No. 31 (briquets)	489, 491										
No. 33 (briquets)	513										
Collinsville	503										
Indiana:											
No. 4	166										
No. 7 A (briquets)	288										
No. 15	429	41	43.28	14.04	11.49	83.4	65.34	2.7	.11	8.80	Automatic air admission operated on all the coal tests.
No. 16	427										
No. 19 (briquets)	464										

TABLE 41.—*Results of tests showing less than 6 per cent black smoke*—Continued.

Field designation of fuel.	No. of test.	Clinker in refuse.	Volatile matter in combustible.	Ash in dry coal.	Moisture in coal as received.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Remarks.
Indian Territory:		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
No. 2 B (briquets)	453										
No. 9	449	.....	37.14	7.64	3.50	101.4	67.54	2.5	.09	7.77	Coal burned with short flame; automatic air admission not operated.
No. 9 (briquets)	450										
Kansas:											
No. 2 B (briquets)	487, 488										
No. 2 B (washed; briquets)	495	46	39.02	16.50	7.24	96.7	65.88	1.3	.03	8.42	Burned with short flame; automatic air admission not operated.
Maryland:											
No. 1 (washed)	231										
No. 2	490	35	19.42	9.16	4.29	110.3	68.76	1.6	.05	9.46	Coal burned slowly; automatic air admission operated on one of the coal tests.
No. 2 (briquets)	493										
Missouri:											
No. 5	320										
No. 10 (briquets)	486	.....	45.11	18.92	8.38	93.4	60.50	1.3	.01	15.63	Coal caked in fire; automatic air admission operated.
New Mexico: No. 3 B	389	0	40.94	17.87	3.01	98.5	68.45	0	.....	.....	Free-burning coal; long flaming; furnace doors cracked after each firing.
Pennsylvania:											
No. 8	236, 237										
No. 15	472, 473										
No. 15 (briquets)	467										
No. 16 (briquets)	468										
No. 18 (briquets)	499, 515										
No. 19	498	40	25.30	8.86	3.75	101.8	65.72	1.7	.08	9.23	Coal caked and burned with short flame; automatic air admission not operated.
No. 19 (briquets)	508										
No. 20 (briquets)	514										
No. 20 (washed; briquets)	512										
No. 22 (briquets)	510										
Tennessee:											
No. 1 (washed; briquets)	409										
No. 5	352										
No. 6	379, 381										Test 352, coal burned rapidly; automatic air admission operated. Tests 379 and 381, coal caked in fire; burned with short to medium flame; automatic air admission operated. Test 388, furnace doors cracked after each firing.
No. 8 (washed)	388	47	37.34	13.40	3.32	96.2	66.79	0	.05	8.11	
No. 9 B (washed; briquets)	393										
No. 10 (washed; briquets)	407, 408										
Utah: No. 2 (briquets)	402, 404	0	47.44	6.99	10.73	74.8	56.21	0	0	4.58	Short flame; automatic air admission not operated.

Virginia:											
No. 5 A	476	49	20.57	14.96	4.51	120.6	66.35	1.5	.10	7.67	Automatic air admission not operated.
No. 5 B (briquets)	494										
No. 6	507										
Washington: No. 2 (briquets)	412	26	43.34	11.36	2.66	99.3	66.06	0	.06	.....	Do.
West Virginia: No. 19	285,289	52	24.71	6.80	2.76	80.7	70.71	0	.02	6.69	Coal burned slowly; caked; automatic air admission not operated.
Wyoming:											
No. 2 B	210	30	50.21	20.33	12.34	77.7	64.34	0	.08	10.52	Coal burned with short flame; automatic air admission operated.
No. 3	211										
Average by States	.....	38	34.51	13.25	6.03	95.1 a 96.6	65.93 a 66.93	1.1	.07	8.56	
Average of 84 tests	.....	43	34.85	12.07	7.22	94.8 a 95.4	65.61 a 65.97	1.4	.07	8.64	

a Tests on Missouri and Utah fuels omitted.

TABLE 42.—*Results of tests on briquetted coals.*

Field designation of coal.	Size of briquets.	No. of test.	Kind of draft.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.
				Per cent.	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Alabama:										
No. 2 B	Large and small	410	Natural	23.5	37.64	100.5	67.24	2.5	0.05	.....
No. 4	do	413								
Illinois:										
No. 6 B	Large	313	12 natural, 4 forced	45.5	42.68	97.4	64.08	4.9	.08	9.04
No. 9 C	do	492, 497								
No. 11 C	do	312								
No. 12 B	Small	463								
No. 21	Large	318								
No. 23 B	do	321, 322								
No. 28 A (washed)	Large and small	459								
No. 28 B	do	457								
No. 29 A (washed)	do	465								
No. 29 B	Small	466								
No. 30 (washed)	Large	511								
No. 31	Large and small	489, 491								
No. 33	Large	513								
Indiana:										
No. 7 A	do	288	Natural	35.0	44.40	88.2	65.30	2.8	.05	8.19
No. 19	Small	464								
Indian Territory:										
No. 2 B (lump)	Large and small	455	do	29.8	35.68	100.7	65.19	5.6	.13	9.72
No. 2 B (slack)	Small	453								
No. 2 B (washed, slack)	Large	456								
No. 8 (washed)	Small	437								
No. 9	do	450								
Kansas:										
No. 2 B	Large	487	do	45.7	39.02	96.7	65.88	1.3	.03	8.42
Do	Small	488								
No. 2 B (washed)	Large	495								
Maryland: No. 2	do	493	do	56.0	22.99	121 2	69.18	0	.02	8.42
Missouri: No. 10	Large and small	486	do	.....	46.20	92.0	56.13	2.5	.02	20.09
Pennsylvania:										
No. 6	Large	333	8 natural, 1 forced	39.4	28.56	109.2	65.90	2.8	.11	8.81
No. 15	Small	467								
No. 16	Large and small	468								
No. 18	Small	499								
Do	Large	515								
No. 19	do	508								
No. 20 (washed)	do	512								
No. 20	Small	514								
No. 22	Large	510								

Tennessee:										
No. 1 (washed)	do	409								
No. 4	Large and small	405								
No. 7 B (washed)	Large	406	Natural	35.5	38.71	101.6	67.10	1.8	.01	5.50
No. 9 B (washed)	do	393								
No. 10 (washed)	do	407								
Do	Small	408								
Virginia: No. 5 B	Large and small	494	do	46.0	19.39	100.4	68.52	0	.10	6.20
Washington: No. 2	do	412	do	26.0	43.34	99.3	66.06	0	.06	
Average (by States)				38.2	36.20	100.6	65.51	2.2	.06	9.37
Average of 47 tests				39.7	37.50	100.7	65.37	3.4	.07	8.68

Table 42 is a compilation of results from all tests made on briquets at the St. Louis fuel-testing plant. The briquets all had a pitch binder and gave off little or no smoke, showing that the tile-roofed furnace used is satisfactory for burning such briquets. The volatile matter in the combustible varied from 23 to 46 per cent and averaged about 38 per cent. The smokeless combustion of coals so high in volatile shows that briquetting has an appreciable effect on burning, especially in the furnaces of steam boilers at the rates of combustion common in stationary practice. The average percentage of the rated capacity developed on these tests was 100.6.

Table 43 is compiled from results of tests made on raw coals and the same coals washed. All the coals were washed at the fuel-testing plant, and the reductions or additions in moisture, ash, and sulphur are of interest. Most of the washed coal either burned freely (was noncoking) or seemed to burn more rapidly than the raw coal. In fact, the average percentage of rated capacity developed was considerably greater with the washed than with the unwashed coal. This result does not indicate that the combustion chamber was more effective in one case than in the other, for the table shows that the washed coals burned with lower efficiency and made more smoke.

The average results show that the washed coals developed 96.6 per cent of the rated capacity, with an efficiency of 64.82 per cent, and the unwashed coals 89.9 per cent of the rated capacity, with an efficiency of 66.95 per cent. This difference in efficiency in favor of raw coal is more consistent and greater with the poorer coals than with the best.

The table emphasizes the difficulty of burning wet coal in any but a properly designed furnace. However, with a good furnace washing should be of advantage, as the washed coal burns more rapidly than the unwashed.

Table 44 is compiled from the results of tests made on the same coals raw and briquetted, natural draft being used in every test but one. It shows that the briquets usually burned with 1 to 3 per cent greater efficiency, developed higher capacity, and were consumed much more completely than the raw coal. Briquetting thus offers to hand-fired plants a means of developing high capacity. The plant can be run practically without smoke and obtain good efficiency by the use of briquets.

Table 45 is a comparison of results of tests made on the same coals burned with natural and with forced draft. Whenever forced draft was used the attempt was made to attain high capacity. Usually this was accomplished at the expense of efficiency. In the tests with forced draft the average percentage of black smoke was about double that in those with natural draft. The combustion space not being

designed for high rates of combustion, an average variation in capacity of 92.6 to 108.4 caused an average drop in efficiency from 64.31 to 60.94. This table demonstrates that forced draft supplied through the average grate and fuel bed will neither intimately mix the air and gases nor allow coal to be burned at high and low rates of combustion with equal efficiency.

Table 46 is a comparison of results of tests of the same coals burned on flat and on rocking grates. In all the tests but one higher efficiency (from 1 to 5 per cent, with an average of 2) was obtained with the rocking grate. The average difference in proportion of rated capacity developed was about 2 per cent and was in favor of the flat grate. However, as the rocking grate had an area of 36.4 square feet and the flat grate of 40.55 square feet, it is evident that the rate of combustion per square foot of grate area was at least equal on the rocking grate to that on the flat grate, or perhaps slightly greater, but as the total weight of coal burned on the flat grates was greater it involved an increased tax on the efficiency of the combustion space. The average figures for over-all efficiency of the plant show that more coal was lost in the ash pit with the rocking grate than with the flat grate, but this loss did not counterbalance the efficiency, which still shows a gain of a little more than 1.50 per cent in favor of the rocking grate.

The ash in the dry coal varied from 5.39 to 23.16 per cent and the sulphur from 0.58 to 4.78 per cent. In the sole test in which the rocking grate failed to show better results the dry coal contained about 4.50 per cent of sulphur. With both flat and rocking grates the sulphur caused trouble. The clinker fused to the grate bars so that the rocking grate as constructed was practically inoperative and was actually used as a flat grate. However, as more difficulty was experienced in getting the clinker off the rocking grate, the time of cleaning and inefficient operation was longer with that grate and the tests showed less efficiency, but as most plants would not have a rocking grate to burn coal so high in sulphur, this point is unimportant. In practice about 2 per cent of sulphur is assumed to be the maximum content desirable for a coal to be burned on rocking grates, but this limit may be exceeded if experience shows that the sulphur is in organic form or that the sulphur and ash combined have no ill effects. The high sulphur and ash in the Wyoming coal did not cause trouble; in fact, the test was exceptional, for the coal did not clinker at all.

The black smoke was about 5 per cent less in the rocking-grate tests than in those with the flat grate. While this reduction is small the gain in efficiency with the rocking grate shows the advantage of having some means of keeping the fire clean. Such a grate would be of value in hand-fired plants for decreasing smoke and increasing the efficiency of operation.

TABLE 43.—*Comparison of results of tests on washed and raw coals.*

Field designation of coal.	No. of test.	Description of coal.	Moisture in coal as fired.	Ash in coal as fired.	Sulphur in coal as fired.	Sulphur in dry coal.	Ash in dry coal.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72 *.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Remarks.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	
Illinois:															
No. 20	301	Washed	16.51	10.45	3.25	3.89	12.51	45	44.04	99.3	63.71	32.5	0.16	9.23	Coal free burning; automatic air admission not operated.
	292	Raw	14.52	15.49	4.32	5.05	18.12	55	45.69	66.3	66.51	0	.02	6.96	Automatic air admission operated.
No. 22 A	328	Washed	14.35	8.22	3.75	4.38	9.60	53	47.60	121.8	61.88	27.0	0	14.14	Coal free burning; automatic air admission operated.
	325	Raw	10.53	13.80	6.07	6.78	15.43	60	47.09	101.0	66.09	25.6	.16	9.07	Automatic air admission operated.
No. 23 A	317	Washed	14.64	8.88	3.23	3.78	10.40	50	46.71	90.4	62.97	0	0	10.80	Coal free burning; automatic air admission operated.
	306	Raw	14.49	13.45	4.62	5.40	15.73	66	44.92	84.3	68.31	15.5	.05	7.45	Do.
Indiana:															
No. 4	154	Washed	14.80	7.19	2.12	2.49	8.44	44	42.43	95.3	64.96	19.2	.18	12.02	Coal burned rapidly; caked; automatic air admission operated.
	165	Raw	13.82	17.26	2.43	2.82	20.03	53	42.25	88.9	70.13	16.1	.09	7.76	Coal caked; automatic air admission operated.
No. 6	159	Washed	11.27	9.63	3.57	4.02	10.85	51	47.92	96.7	60.37	43.4	.60	17.79	Coal burned rapidly; caked; automatic air admission operated.
	157	Raw	10.51	12.76	4.55	5.08	14.26	53	45.35	84.9	64.36	18.6	.23	9.40	Coal burned slowly; caked; automatic air admission operated.
No. 8	184	Washed	11.87	9.29	2.87	3.26	10.54	50	47.15	97.0	65.60	44.8	.25	10.26	Coal burned freely; automatic air admission operated.
	185	Raw	10.12	12.89	3.54	3.94	14.34	54	46.17	89.0	63.11	19.4	.17	12.65	Automatic air admission operated.
No. 10	177	Washed	10.98	6.24	3.50	3.93	7.01	51	49.69	105.3	58.72	46.6	.53	18.34	Coal burned freely; automatic air admission operated.
	167	Raw	10.60	10.16	4.21	4.71	11.36	49	47.83	99.4	66.60	36.6	.24	12.51	Coal burned rapidly; caked; automatic air admission operated.
No. 12	310	Washed	12.87	7.94	3.02	3.47	9.11	26	45.27	97.8	68.06	16.0	.14	15.83	Coal burned freely; automatic air admission operated.
	300	Raw	12.41	13.86	4.21	4.81	15.82	30	46.28	103.9	67.15	31.4	.08	6.00	Coal burned freely; automatic air admission not operated.
Kansas: No. 6	323	Washed	11.71	10.45	2.64	2.99	11.83	57	38.84	106.6	64.31	38.3	.30	13.71	Coal burned freely; automatic air admission operated.
	311	Raw	8.28	15.53	3.42	3.73	16.93	56	39.81	82.2	64.28	7.0	.09	10.59	Automatic air admission operated.

Maryland: No. 1	232	Washed	3.43	10.13	1.10	1.14	10.48	22	16.29	93.2	67.64	7.5	.08	12.86	Automatic air admission not operated.
	222	Raw	1.84	12.52	1.52	1.55	12.76	38	16.38	80.1	65.28	8.2	.10	12.63	Coal burned slowly; caked; automatic air admission not operated.
New Mexico:															
No. 3 B	392	Washed	4.77	12.23	.71	.75	12.85	0	39.88	119.2	65.48	26.0	.12	7.30	Coal burned quickly; caked; furnace door cracked after each firing.
	391	Raw	2.47	16.91	.67	.69	17.34	0	40.92	114.8	69.18	24.5	.....	.....	Coal burned quickly; furnace door cracked after each firing.
No. 4 A	398	Washed	3.86	11.40	.63	.66	11.86	0	40.19	108.1	65.83	21.0	.12	9.34	Coal burned freely; automatic air admission not operated.
	397	Raw	2.30	14.58	.60	.61	14.92	0	41.61	103.9	63.86	16.5	.12	9.69	Do.
Ohio:															
No. 2	197	Washed	8.99	7.74	3.15	3.46	8.50	50	45.29	84.4	62.54	32.2	.15	15.17	Coal burned freely; clinker fused into grate; automatic air admission operated.
	193	Raw	8.86	13.81	4.37	4.79	15.15	42	45.27	80.3	64.33	27.6	.11	14.82	Clinker fused into grate; automatic air admission operated.
No. 4	220	Washed	4.30	6.69	2.97	3.10	6.99	34	43.66	93.2	63.19	39.2	.17	16.02	Coal caked in fire; automatic air admission operated.
	201	Raw	3.73	9.73	2.65	2.75	10.11	51	42.44	93.2	66.14	25.8	.14	13.35	Coal burned freely; automatic air admission operated; clinker adhered to grate.
No. 6	253	Washed	3.26	6.88	3.01	3.11	7.11	60	43.11	79.4	64.08	23.2	.23	9.85	Clinker adhered to grate; automatic air admission operated.
	284	Raw	3.71	12.07	3.77	3.91	12.54	52	43.43	81.3	69.01	13.1	.13	4.12	Coal burned freely; automatic air admission not operated.
No. 9 B	241	Washed	7.92	7.08	2.86	3.11	7.69	56	45.39	92.7	67.13	39.6	.07	9.85	Coal burned freely; automatic air admission operated.
	224	Raw	7.84	14.89	3.27	3.55	16.16	48	45.61	87.8	66.61	22.4	.05	11.14	Coal caked; automatic air admission operated.
Pennsylvania:															
No. 5	195	Washed	2.97	4.73	.94	.97	4.88	40	38.04	96.9	65.33	43.8	.44	15.11	
	286	Raw	4.11	7.95	1.01	1.05	8.29	45	36.97	95.9	71.97	15.1	.21	4.59	Coal free burning; automatic air admission not operated.
No. 7	199	Washed	4.80	10.94	1.62	1.70	11.50	33	26.87	88.6	67.24	10.8	.04	12.71	Coal caked; automatic air-admission operated.
	307	Raw	5.80	13.63	2.22	2.36	14.47	0	27.04	85.0	68.51	8.0	.04	6.40	Coal burned slowly; automatic air admission operated.
Tennessee: Nos. 8 A and 8 B.	388	Washed	2.83	10.23	2.92	3.00	10.53	51	39.91	106.1	67.17	0	.....	.....	Coal burned quickly; caked; furnace door cracked after each firing.
	384	Raw	2.40	14.87	5.28	5.41	15.24	57	39.42	72.8	65.37	10.5	0	15.24	Coal caked; automatic air admission operated; clinker adhered to grate.
Virginia: No. 2	260	Washed	3.34	4.48	.85	.88	4.63	40	39.21	87.7	65.94	40.8	.19	13.71	Coal burned freely; automatic air admission operated.
	256	Raw	4.22	6.19	.82	.86	6.46	47	37.37	87.6	65.93	32.8	.26	11.69	Coal caked in fire; automatic air admission operated.

TABLE 43.—*Comparison of results of tests on washed and raw coals*—Continued.

Field designation of coal.	No. of test.	Description of coal.	Moisture in coal as fired.	Ash in coal as fired.	Sulphur in coal as fired.	Sulphur in dry coal.	Ash in dry coal.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Remarks.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	
West Virginia:															
No. 17	230	Washed	4.35	6.17	1.36	1.42	6.45	48	31.68	89.0	67.94	23.8	.02	11.91	Coal burned slowly; automatic air admission operated.
	226	Raw	4.10	7.40	1.21	1.26	7.72	34	31.55	87.6	67.81	7.8	.06	9.37	Coal caked; automatic air admission operated.
No. 20	266	Washed	3.14	5.53	1.10	1.14	5.71	45	36.57	86.7	66.18	21.8	.06	11.73	Automatic air admission operated.
	273	Raw	2.89	8.43	1.50	1.54	8.68	34	35.80	83.6	70.07	12.2	.07	6.04	Coal burned freely; automatic air admission operated.
No. 21	267	Washed	4.24	3.67	1.07	1.12	3.83	52	39.59	95.4	66.81	36.0	.08	9.48	Do.
	296	Raw	3.42	6.12	1.22	1.26	6.34	47	37.87	101.8	69.45	13.5	.26	8.60	Do.
No. 22 A	454	Washed	5.24	6.10	.90	.95	6.44	25	37.98	110.3	65.95	20.0	.25	9.96	Coal caked; automatic air admission operated.
	447	Raw	5.55	13.47	1.04	1.10	14.26	33	36.61	99.1	68.40	13.0	.04	6.71	Do.
No. 23 B	444	Washed	4.06	4.80	.95	.99	5.00	30	39.17	88.0	62.84	8.5	.16	10.66	Coal caked; clinker adhered to grate; automatic air admission operated.
	445	Raw	2.44	10.59	1.40	1.43	10.85	41	38.29	95.9	67.93	27.0	.05	6.97	Coal burned quickly; caked; clinker adhered to grate; automatic air admission operated.
Wyoming: No. 3	223	Washed	19.08	6.78	4.26	5.26	8.38	53	49.34	81.0	63.34	21.0	.30	12.26	Coal burned freely; automatic air admission not operated; clinker adhered slightly to grate.
	212	Raw	13.60	16.21	7.90	9.14	18.76	58	51.46	88.2	64.08	22.7	.13	11.60	Clinker adhered slightly to grate; automatic air admission not operated.
Average		Washed	8.06	7.84	2.24	2.50	8.58	41	40.82	96.6	64.82	26.3	.19	12.40	
		Raw	7.48	12.48	2.99	3.29	13.54	42	40.50	89.9	66.95	18.1	.12	9.41	

TABLE 44.—*Comparison of results of tests on raw and briquetted coals.*

Field designation of coal.	Condition of fuel as fired.	No. of test.	Kind of draft.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72 *.	Black smoke.	CO in dry chimney gas.	Unaccounted for in heat balance.	Remarks.
				Per cent.	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Alabama:											
No. 2 B	Large and small briquets	410	Natural	0	38.94	91.4	69.52	0	0.02	.....	Briquet broken before firing.
	Raw	382	do	53	38.87	108.6	65.44	30.0	.15	13.63	
No. 4	Large and small briquets	413	do	47	36.33	109.5	64.95	5.0	.07	.....	Do.
	Raw	375	do	54	35.41	106.9	66.38	11.5	.05	9.97	Furnace doors cracked for an interval after each firing.
Illinois:											
No. 21	Large briquets	318	Forced	47	41.83	115.3	64.00	0	.02	11.01	Briquets broken before firing.
	Raw	316	Natural	62	42.35	89.3	64.35	0	0	9.61	
No. 29 B	Small briquets	466	do	38	45.79	109.2	66.91	13.0	.04	8.03	
	Raw	461	do	64	45.66	104.2	64.37	7.0	.06	9.80	
Indiana: No. 7 A	Large briquets	288	do	37	42.84	84.5	66.08	0	.07	6.77	Do.
	Raw	158	do	54	47.33	96.9	64.71	45.4	.49	14.84	Coal caked in fire.
Indian Territory:											
No. 2 B	Small briquets from slack coal.	453	do	34	39.88	105.1	69.66	4.5	.06	6.02	
	Raw	418	do	48	40.81	95.0	68.38	15.5	.09	8.91	
No. 9	Small briquets	450	do	.....	19.23	102.2	67.77	0	.05	8.53	
	Raw	449	do	26	15.17	97.0	65.20	3.0	.17	8.77	Clinker adhered to grate.
Maryland: No. 2	Large briquets	493	do	56	22.99	121.2	69.18	0	.02	8.42	Briquets fired whole.
	Raw	490	do	32	18.96	113.9	65.54	4.8	.10	8.69	
Pennsylvania:											
No. 6	Large briquets	333	do	43	39.45	105.9	65.64	15.5	.20	5.83	Briquets broken before firing; test too short for reliable results.
	Raw	217	do	54	38.59	97.1	66.39	37.8	.30	11.04	Coal caked in fire.
No. 15	Small briquets	467	do	39	26.53	99.0	70.08	5.5	.03	7.89	
	Raw	473	do	44	19.92	91.2	66.46	4.5	.08	7.85	Do.
No. 16	Large and small briquets	468	do	41	27.43	105.7	68.22	4.0	.04	10.05	Briquets fired whole.
	Raw	471	do	40	24.24	98.9	69.29	8.0	.02	7.48	Coal caked in fire.
No. 19	Large briquets	508	do	34	37.77	113.7	67.23	0	.02	7.07	Briquets fired whole.
	Raw	498	do	46	35.57	106.8	65.84	4.5	.04	8.65	
Tennessee:	Large briquets (washed)	409	do	26	40.56	110.3	68.06	0	0	.....	Briquets broken before firing.
	Small briquets (washed)	411	do	0	40.31	134.7	70.26	17.0	.10	4.45	Test too short for reliable results.
No. 1	Raw	345	do	44	39.87	111.7	66.09	14.0	.09	.....	
	do	346	do	53	38.83	109.5	67.96	16.5	.05	.....	

TABLE 44.—*Comparison of results of tests on raw and briquetted coals*—Continued.

Field designation of coal.	Condition of fuel as fired.	No. of test.	Kind of draft.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gas.	Unaccounted for in heat balance.	Remarks.
Tennessee—Continued.				*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
No. 4	Large and small briquets	405	...do	25	39.92	105.3	69.00	11.0	0	.....	Briquets broken before firing.
	Raw	355	...do	38	38.44	110.8	67.05	23.5	.27	7.97	Smoked badly for short interval after firing.
Washington: No. 2	Large and small briquets	412	...do	26	43.34	99.3	66.06	0	.06	.....	Briquets fired whole.
	Raw	359	...do	61	43.14	97.4	66.65	33.5	.23	6.41	Cracked furnace door for a short interval after each firing.
Average results	Briquetted coal	.....	.....	32.8	36.44	107.0	67.66	4.7	.05	7.64	
	Raw coal	.....	.....	48.3	35.19	102.2	66.25	16.2	.14	9.54	

TABLE 45.—*Comparison of results of tests of the same fuels when using natural and forced drafts.*

Field designation of fuel.	No. of test.	Kind of draft.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry flue gases.	Unaccounted for in heat balance.
Arkansas:			*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
No. 7 A	294	Forced	57	19.07	85.7	65.07	0	0.02	9.84
	293	Natural	52	19.07	72.8	69.32	0	.11	7.48
No. 8 (washed)	309	Forced	28	12.51	106.3	62.92	0	.57	11.13
	308	Natural	36	13.03	80.9	67.64	0	.03	6.46
Illinois:									
Collinsville	505	Forced	57	45.87	131.6	60.20	14.9	.10	10.58
	500	Natural	55	45.91	112.1	62.53	19.7	.11	5.68
No. 9 C (briquets)	492	Forced	51	45.28	98.2	62.97	4.3	.06	8.85
	497	Natural	36	42.06	85.9	63.37	0	.05	7.03
No. 23 B (briquets)	322	Forced	62	46.61	106.6	58.22	17.0	.14	17.43
	321	Natural	62	46.61	106.0	58.93	22.0	.02	17.05
Missouri, No. 7 (washed)	332	Forced	61	44.48	129.4	56.64	42.5	.17	13.63
	330	Natural	55	45.40	115.0	62.03	27.5	0	13.49
Pennsylvania, No. 17	506	Forced	56	32.54	98.0	63.46	9.0	.04	8.30
	496	Natural	51	33.75	101.0	67.15	7.0	.03	6.63
Tennessee, No. 8	385	Forced	55	39.85	86.5	63.33	28.0	.05	14.80
	384	Natural	57	39.42	72.8	65.37	10.5	0	15.24
West Virginia :									
No. 5 A	482	Forced	62	14.75	147.7	60.23	20.5	.20	15.45
	476	Natural	51	15.18	99.7	67.13	1.5	.16	8.68
No. 15	216	Forced	49	42.92	103.0	60.30	54.6	.45	18.22
	215	Natural	46	42.71	84.4	62.91	46.2	.26	15.31
Wyoming, No. 2 B	213	Forced	0	51.58	99.9	56.98	42.0	.53	19.03
	210	Natural	0	50.01	88.3	61.06	0	.06	16.16
Average of 11 tests		Forced	48.9	35.9	108.4	60.94	21.2	.21	13.39
		Natural	45.5	35.7	92.6	64.41	12.2	.08	10.84

TABLE 46.—*Comparison of results of tests on the same coals with flat and rocking grates.*

Field designation of coal.	No. of test.	Kind of grate.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Sulphur in dry coal.	Ash in dry coal.	Efficiency of boiler and grate.
Illinois:			*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
No. 13 (washed)	145	Rocking	45	38.17	94.7	69.15	28.0	0.34	12.52	1.50	8.03	67.93
	144	Flat	47	39.38	103.8	67.33	36.0	.36	12.05	1.44	8.37	66.12
No. 19 A	171	Rocking	45	35.38	90.6	69.09	13.0	.14	9.81	.58	10.28	67.06
	161	Flat	58	35.53	87.6	68.27	13.0	.13	11.65	.58	10.25	65.82
No. 19 B	205	Rocking	41	36.74	94.9	71.27	28.8	.10	7.37	.61	11.41	68.86
	175	Flat	10	37.65	104.7	69.26	32.0	.21	9.69	.53	11.43	67.50
Indiana:												
No. 4	166	Rocking	44	42.85	74.7	66.38	2.0	.28	8.53	2.96	18.49	62.60
	151	Flat	58	44.15	80.8	64.37	12.8	.19	9.57	2.94	16.57	62.41
No. 7 B	[a] 164	Rocking	43	47.79	75.5	60.89	15.2	.08	19.61	4.39	11.44	59.49
	[a] 176	Flat	42	48.25	78.6	62.18	16.0	.04	13.21	4.60	12.19	60.94
Kentucky: No. 1 C	263	Rocking	49	38.68	78.9	68.44	13.6	.13	6.26	1.03	6.62	66.38
	265	Flat	51	37.98	77.2	65.95	12.0	.12	7.75	1.02	6.82	64.88
Ohio: No. 4	201	Rocking	51	42.44	93.2	66.14	25.8	.14	13.35	2.75	10.11	64.17
	188	Flat	53	42.87	95.0	63.97	33.6	.27	14.25	3.80	10.45	62.26
Virginia: No. 2	256	Rocking	47	37.37	87.6	65.93	32.8	.26	11.69	.86	6.46	64.48
	251	Flat	55	37.43	95.6	65.91	44.4	.04	11.80	.85	6.70	65.24
West Virginia:												
No. 15	214	Rocking	46	42.38	75.2	68.54	32.8	.10	12.21	3.07	8.18	62.76
	215	Flat	46	42.71	84.4	62.91	46.2	.26	15.31	2.84	7.86	61.13
No. 19	285	Rocking	56	22.62	81.8	70.76	0	.04	6.04	.94	6.70	69.04
	289	Flat	48	22.81	79.6	70.65	0	0	7.34	1.07	6.90	68.00
No. 20 (washed)	264	Rocking	33	36.07	90.5	70.23	26.0	.05	8.34	1.10	5.39	69.26
	266	Flat	45	36.57	86.7	66.18	21.8	.06	11.73	1.14	5.71	65.47
Wyoming: No. 2 B	210	Rocking	0	50.01	88.3	61.06	0	.06	16.16	4.37	20.98	58.66
	196	Flat	0	50.05	79.3	58.20	9.6	.11	14.75	4.78	23.16	55.61
Average results of 12 tests		Rocking	41.7	37.54	85.5	67.32	18.2	.14	10.99	2.01	10.34	65.06
		Flat	42.8	37.95	87.8	65.43	23.1	.17	17.40	2.13	10.53	63.78

[a] Clinker fused into grate and was removed with difficulty.

TABLE 47.—*Comparison of results of tests on the same coals showing the variation in boiler efficiency 72* as the percentage of black smoke increases.*

Field designation of fuel.	No. of test.	Kind of draft.	Clinker in ash and refuse.	Volatile matter in combustible.	Ash in dry coal.	Moisture in coal as fired.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Remarks.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Alabama: No. 3	390	Natural	43	36.75	21.42	2.93	92.7	67.43	0	.....	.....	Coal burned freely; furnace doors left open short time after firing.
	394	do	52	37.59	18.97	2.88	94.8	65.62	16.5	0.09	6.35	Automatic air admission not operated; coal high in slack; caked.
No. 4	378	do	54	35.24	13.97	5.27	77.4	65.61	0	0	11.89	Automatic air admission operated; coal burned rapidly; caked.
	376	do	44	34.83	15.02	4.84	83.2	65.82	6.5	.08	10.08	Furnace doors left open short interval after each firing; coal caked in fire.
	375	do	54	35.41	10.92	4.04	106.9	66.38	11.5	.05	9.97	Furnace doors left open short interval after each firing.
Indiana: No. 4	166	do	44	42.85	18.49	14.79	74.7	66.38	2.0	.28	8.53	Automatic air admission operated.
	165	do	53	42.25	20.03	13.82	88.9	70.13	16.1	.09	7.76	Coal caked; automatic air admission operated.
No. 15	429	do	41	41.16	9.44	12.83	87.9	64.43	0	.09	9.46	Automatic air admission operated.
	428	do	53	40.12	10.16	13.05	95.6	64.31	11.5	.13	8.92	Coal burned rapidly; automatic air admission operated.
No. 16	427	do	50	43.59	14.21	10.09	78.6	65.32	6.0	.09	9.64	Automatic air admission operated.
	426	do	53	44.89	13.75	9.09	89.1	66.30	16.5	.09	9.43	Do.
Indian Territory: No. 2 B (briquets).	453	do	34	39.88	8.59	3.29	105.1	69.66	4.5	.06	6.02	Small briquets; burned quickly; clinker adhered to grate; automatic air admission used for short period.
	455	do	26	40.16	8.28	2.70	93.5	60.41	8.0	.34	13.59	Both round and square briquets; automatic air admission operated on part of test; clinker adhered to grate.
Maryland: No.1 (washed)	231	do	17	16.31	11.12	3.70	95.9	68.56	0	.04	11.28	Volatile matter burned off quickly; automatic air admission on only short time after firing.
	232	do	22	16.29	10.48	3.43	93.2	67.64	7.5	.08	12.86	Automatic air admission not operated.
Missouri: No. 5	320	do	63	44.03	18.36	12.24	94.7	64.87	0	0	11.17	Coal burned quickly; caked; automatic air admission operated.
	319	do	61	44.16	17.76	13.37	78.1	63.28	7.2	.04	9.58	Automatic air admission operated; coal caked.

TABLE 47.—*Comparison of results of tests on the same coals showing the variation in boiler efficiency 72* as the percentage of black smoke increases*—Continued.

Field designation of fuel.	No. of test.	Kind of draft.	Clinker in ash and refuse.	Volatile matter in combustible.	Ash in dry coal.	Moisture in coal as fired.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Remarks.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Tennessee: No. 5	352	Natural	47	39.72	10.34	5.59	95.4	65.62	0	0.21	9.86	Coal burned rapidly; automatic air admission operated.
	358	do	42	39.11	9.98	6.73	115.5	66.83	14.5	.10	7.91	Automatic air admission operated; coal burned freely.
	357	do	46	39.37	9.41	5.82	111.2	62.73	16.5	.18	10.31	Do.
Virginia: No. 5 A	476	Natural and forced.	51	15.18	19.50	4.73	99.7	67.13	1.5	.16	8.68	Automatic air admission not operated; forced draft used for 2 hours.
	482	Forced	62	14.75	18.22	4.60	147.7	60.23	20.5	.20	15.45	Coal burned rapidly; automatic air admission not operated.
Wyoming: No. 2 B	210	Natural	0	50.01	20.98	9.55	88.3	61.06	0	.06	16.16	Coal burned freely; automatic air admission operated.
	213	Forced	0	51.58	23.57	8.94	99.9	56.98	42.0	.53	19.03	Maximum capacity test; automatic air admission not operated.
No. 3	211	Natural	60	50.40	19.67	15.12	67.0	67.62	0	.10	4.88	Clinker adhered to grate; automatic air admission operated.
	212	Natural and forced.	58	51.46	18.76	13.60	88.2	64.08	22.7	.13	11.60	Clinker adhered to grate; automatic air admission not operated.

Table 47, compiled from the results of tests made on the same coals, shows the variation in boiler efficiency as the smoke increases. The tests of each coal compared were made with the same boiler and same grate. All the tests but two were made with natural draft; but inasmuch as the use of forced draft only increased the rate of combustion, as was shown by Table 45, the tests are comparable both as to efficiency and smoke.

In general the results show that as the percentage of rated capacity developed increased the percentage of black smoke increased and the efficiency decreased. This proves that the combustion space was not efficient over a wide range of working conditions, but there was a limit for rate of combustion for each kind of coal, above which efficient operation was impossible. The table also demonstrates that with hand-fired furnaces the combustion space to be most efficient must have some means of mixing the air and gases. The results with Maryland and Indian Territory coals show that the most smoke was made on the tests showing low capacity. Methods of operation may account for this efficiency variation, as with the Maryland coal the automatic air admission was used on the high-capacity test and not on the low. The discordant results in the tests of Indiana coals are probably due to the variation in air admission. The beneficial effect of the automatic air admission in reducing the smoke and increasing efficiency is noticeable in several tests.

The three tests on Alabama coal were run at about equal efficiency over a wide range of capacity, but as the methods of operating were dissimilar these apparent discrepancies could easily result.

High smoke values gave high unaccounted for values in the heat balance. Usually the percentage of CO in the flue gas was much greater when the smoke was high, showing a cause for the decreasing efficiency and increasing visible evidence of loss noted with high rates of combustion.

COMPARISON OF METHODS OF SUPPLYING AIR FOR COMBUSTION.

METHODS COMPARED.

As supplementing the data already presented to show the results obtained in tests at the fuel-testing plants, a number of tables have been compiled to show the relative value of different methods of supplying air for combustion. The following methods are compared: (1) Air supplied continuously by means of openings in grates; (2) air taken continuously through the grates and an extra amount supplied automatically at times of greatest distillation of volatile matter; (3) air taken continuously through the grates and more supplied at times of firing by cracking the furnace doors. All full-length St. Louis tests (except the briquet tests) and the hand-fired Norfolk tests have been used in this compilation.

RELATION OF EFFICIENCY TO CAPACITY WITH AIR ADMITTED THROUGH GRATES AND BY AUTOMATIC DEVICES.

To permit fair comparison of the boiler efficiency and rated capacity developed, tests were selected on which the same kind of coal was used and the same method of supplying air for combustion. These tests include two series, one in which the automatic air-admission device for the furnace was not operated and another in which it was. The results of the first series are given in the following table:

TABLE 48.—*Relation of efficiency to capacity, automatic air-admission device not operated.*

Kind of coal.	Percentage of rated capacity developed.	Efficiency 72*.	Kind of coal.	Percentage of rated capacity developed.	Efficiency 72*.
		Per cent.			*Per cent.*
Arkansas	106.3	62.92	Virginia	101.8	63.39
Do	85.7	65.07	Do	99.7	67.13
Do	85.0	65.90	Do	92.3	68.25
Do	80.9	67.64	Do	81.6	65.77
Do	72.8	69.32	Wyoming	99.9	56.98
New Mexico	108.2	67.19	Do	95.2	59.63
Do	108.1	65.83	Do	93.1	57.84
Do	103.9	63.86	Do	88.2	64.08
Virginia	147.7	60.23	Do	81.0	63.34

The above table shows that, in general, when the air was supplied by means of the air spaces in the grates the boiler efficiency was highest at the lowest capacities and decreased as the capacity increased.

Data from the second series of selected tests are presented in Table 49.

TABLE 49.—*Relation of efficiency to capacity, automatic air-admission device operated.*

Kind of coal.	Percentage of rated capacity developed.	Efficiency 72*.	Kind of coal.	Percentage of rated capacity developed.	Efficiency 72*.
		Per cent.			*Per cent.*
Maryland	113.9	68.54	Wyoming	88.3	61.06
Do	93.2	67.64	Do	79.3	58.20
Do	80.1	65.28	Do	67.0	67.62

This table shows that the automatic air admission is not always of equal value. With the Maryland coal too much air was supplied at the capacity of 80.1 per cent, for even at the highest capacity given neither the greatest possible reduction of air supply nor the highest efficiency had been reached. With the Wyoming coal not enough air was supplied at 88.3 per cent capacity to maintain the same efficiency as at 67 per cent.

COMPARISON OF RESULTS FROM DIFFERENT COALS WITH VARIED AIR ADMISSION.

In Table 50 the volatile matter in the coal as received, the percentage of rated capacity developed, the efficiency 72*, and the smoke readings have been averaged for the coals from each State according to the method of supplying air for combustion. The data show that no unvarying rule can be formulated to cover all coals, but in general a higher capacity and a higher efficiency resulted when additional air was supplied at times of firing. Many of the smoke averages do not fall as might be expected.

TABLE 50.—*Relation of air admission to results when burning different coals.*

Kind of coal.	Method of supplying air.	Number of tests.	Volatile matter in coal as fired.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.
			Per cent.		*Per cent.*	*Per ct.*
Alabama	Automatic air admission off	5	27.3	95.5	66.56	14.4
	Automatic air admission on	2	29.7	78.3	65.92	0
	Furnace doors cracked after firing.	4	28.1	98.8	66.88	8.0
Arkansas	Automatic air admission off	6	15.0	89.1	65.18	0
Illinois	....do	32	32.5	91.7	58.56	24.7
	Automatic air admission on	40	32.2	91.9	66.05	18.3
	Furnace doors cracked after firing.	11	31.6	92.7	65.04	5.4
Indiana	Automatic air admission off	1	34.1	103.9	67.15	31.4
	Automatic air admission on	35	34.8	90.1	65.13	21.9
	Furnace doors cracked after firing.	1	33.5	93.1	65.36	28.2
Indian Territory	Automatic air admission off	1	13.6	97.0	65.20	3.0
	Furnace doors cracked after firing.	1	35.4	90.5	68.10	19.5
West Virginia (Jamestown)	Automatic air admission off	2	16.9	128.5	66.99	6.9
	Automatic air admission on	2	17.1	80.8	66.93	7.0
	Furnace doors cracked after firing.	1	15.3	78.3	68.61	8.6
Kansas	Automatic air admission on	13	33.1	92.2	66.47	20.1
	Furnace doors cracked after firing.	1	33.7	68.4	67.08	.....
Maryland	Automatic air admission off	3	15.0	95.7	67.15	6.8
	Automatic air admission on	1	14.0	95.9	68.56	0
Missouri	Automatic air admission off	1	32.0	129.4	56.64	42.5
	Automatic air admission on	6	32.5	97.7	63.12	12.8
Montana	Automatic air admission off	2	31.7	114.3	66.95	15.3
New Mexico	....do	3	33.8	106.7	65.63	17.3
	Furnace doors cracked after firing.	4	32.6	107.9	67.08	17.8
Ohio	Automatic air admission off	1	36.6	81.3	69.01	13.1
	Automatic air admission on	24	36.6	92.1	65.69	33.1
	Furnace doors cracked after firing.	2	39.0	118.4	68.02	13.0
Pennsylvania	Automatic air admission off	12	22.7	91.4	67.43	6.2
	Automatic air admission on	10	31.2	93.5	67.67	23.7
Tennessee	Automatic air admission off	4	32.8	89.8	65.71	20.1
	Automatic air admission on	12	32.1	103.0	66.02	14.2
	Furnace doors cracked after firing.	7	33.0	110.2	65.16	21.9
Texas	Automatic air admission off	2	30.6	96.6	56.69	6.0
Virginia	....do	5	22.5	104.6	64.95	10.4
	Automatic air admission on	9	34.7	92.3	66.77	34.2
Washington	Automatic air admission off	1	35.6	108.4	63.98	17.0
	Automatic air admission on	1	34.5	81.8	65.04	10.0
	Furnace doors cracked after firing.	1	36.5	97.4	66.65	33.5
West Virginia	Automatic air admission off	2	20.6	80.7	70.71	0
	Automatic air admission on	27	32.7	93.8	67.59	21.5
	Furnace doors cracked after firing.	2	34.3	103.9	69.10	16.0
Wyoming	Automatic air admission off	5	37.0	91.5	60.37	21.6
	Automatic air admission on	3	35.0	78.2	62.29	3.2

RELATION OF EFFICIENCY TO CAPACITY WITH VARIED AIR ADMISSION.

Table 51 gives averages for all tests made with automatic air admission not operated, automatic air admission operated, and furnace doors cracked, not classified according to States.

TABLE 51.—*Relations of air supply to averages of results.*

Method of supplying air.	Number of tests.	Volatile matter in coal as fired.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	
					Amount.	Number of tests.
		Per cent.		*Per cent.*	*Per cent.*	
Automatic air admission off	88	28.0	93.8	62.95	11.8	59
Automatic air admission on	185	33.2	92.9	66.06	21.6	162
Furnace doors cracked	35	31.2	99.7	66.21	15.4	28

The subjoined list shows the names of the coals which fell in the final grouping of Table 51:

AUTOMATIC AIR ADMISSION NOT OPERATED.

Indian Territory.
Arkansas.
Maryland.
West Virginia (Jamestown).
West Virginia.
Virginia.
Pennsylvania.
Alabama.
Texas.
Illinois.
Missouri.
Montana.
Tennessee.
Indiana.
New Mexico.
Washington.
Ohio.
Wyoming.

AUTOMATIC AIR ADMISSION OPERATED.

Maryland.
West Virginia (Jamestown).
Alabama.
Pennsylvania.
Illinois.
Missouri.
Tennessee.
West Virginia.
Kansas.
Indiana.
Virginia.
Washington.
Wyoming.
Ohio.

FURNACE DOORS CRACKED.

West Virginia (Jamestown).
Alabama.
Illinois.
New Mexico.
Indiana.
Kansas.
Tennessee.
West Virginia.
Indian Territory.
Washington.
Ohio.

Tables 52 to 54 give averaged results showing the relation of efficiency to capacity under the three methods of air admission when high-volatile coals are burned, all the tests on low-volatile coals being excluded.

TABLE 52.—*Relation of efficiency to capacity, automatic air admission not operated.*

Percentage of rated capacity developed.	Efficiency 72*.	Percentage of rated capacity developed.	Efficiency 72*.
	Per cent.		*Per cent.*
108.4	63.98	96.6	56.69
106.3	61.97	95.5	66.56
105.3	66.39	86.4	64.69
98.0	66.19	80.7	70.71

Table 52 shows that the highest efficiency was obtained with the lowest capacity and that the efficiency decreased as the capacity increased.

TABLE 53.—*Relation of efficiency to capacity, automatic air admission operated.*

Percentage of rated capacity developed.	Efficiency 72*.	Percentage of rated capacity developed.	Efficiency 72*.
	Per cent.		*Per cent.*
96.6	65.70	88.1	65.65
93.5	67.67	78.3	65.92
92.2	66.47	78.2	62.29
92.1	65.69		

Table 53 shows that the lowest efficiency was obtained when running at the lowest capacity and that the efficiency increased as the capacity increased.

TABLE 54.—*Relation of efficiency to capacity, furnace doors cracked after each firing.*

Percentage of rated capacity developed.	Efficiency 72*.	Percentage of rated capacity developed.	Efficiency 72*.
	Per cent.		*Per cent.*
118.4	68.02	97.4	66.65
107.9	67.08	92.7	65.04
103.9	69.10	90.6	65.87
98.8	66.88	90.5	68.10

Table 54 shows that the highest efficiencies were obtained when running at high capacity and that with one exception, the reverse was true. Supplying air by cracking the door, while it results in high efficiency, is more liable to furnish a variable supply than an automatic device, as it introduces the personal element.

With the furnace door cracked after firing, the lowest efficiency was 65 per cent. With the automatic air admission operated, the lowest efficiency was 62.3 per cent. With the automatic air admission not operated, the lowest efficiency was 56.7 per cent.

CONCLUSIONS.

Air supply should be regulated to suit the combustion of different kinds of coal.

With the same coal burned in the same furnace, a proper amount of air supplied at times of greatest distillation of volatile matter will aid in obtaining higher capacity and higher efficiency than can be had without such regulation.

When air is supplied in the same manner to the same coal in the same furnace, the efficiency is practically determined by the rate of combustion.

On the average, cracking the furnace door resulted in highest capacities with the highest efficiencies, from which it would seem that

in general not enough air was supplied by the automatic air-admission openings.

Air should be supplied automatically to the furnace, as this overcomes in a measure the personal element.

In the average furnace the gases and air are not mixed thoroughly and it is possible, especially by cracking the furnace doors, to admit large amounts of air into the furnace and reduce the visible products of incomplete combustion at the expense of efficiency. (See tests of Illinois coal in Table 50.)

INFLUENCE OF VOLATILE MATTER IN FUEL ON THE SMOKE PROBLEM.

From a study of the tables giving the results of the tests made under Heine boilers, it appears that in all tests coal with low volatile matter was burned most efficiently and with the least smoke. High-volatile coals are more difficult to burn without loss than low-volatile coals, but the difficulty is not directly proportional to the percentage of volatile matter. Some coals with less than 30 per cent of volatile matter give off more smoke than others having 40 per cent. Observations of the behavior of coals when thrown into the furnace indicated that some coals gave off their volatile matter at lower temperatures than others, and that there was a difference in the nature of the volatile matter.

This phase of the composition of coals is now undergoing laboratory investigation under the direction of N. W. Lord. When these investigations are completed valuable data will be at the command of engineers who are called on to design furnaces for burning coal. Horace C. Porter, who is conducting the experiments, has furnished the following preliminary statement, which shows that among the coals tested there is a wide difference in the character of the volatile matter:

TABLE 55.—*Results of heating 10 grams of air-dried coal ten minutes.*

Kind of coal.	Highest temperature in coal in retort.	Tar.[a]	Water.	Gas.	Gas composition (calculated to undiluted gas).						
					CO_2.	Illuminants.[a]	CO.	CH_4.	C_2H_6.[a b]	H_2.	N_2.
At heating temperature of 500° C.	° C.	P. ct.	P. ct.	C.c.							
Connellsville, Pa	335	.....	.....	8	30.0	0	6.5	6.5	7.0	0	[c] 50.0
Zeigler, Ill	325	.....	.....	90	14.8	0	5.3	8.0	.....	0	[c] 71.9
At heating temperature of 600° C.											
Connellsville, Pa	441	4.9	3.2	190	6.3	8.2	5.9	36.9	23.7	2.0	[c] 17.0
Zeigler, Ill	440	6.8	13.0	173	15.7	7.0	14.4	19.0	22.2	2.8	[c] 18.9

[a] Smoke-forming matter.
[b] Includes all higher paraffin calculated as C_2H_6.
[c] Includes small amount of air.

TABLE 55.—*Results of heating 10 grams of air-dried coal ten minutes*—Continued.

Kind of coal.	Highest temperature in coal in retort.	Tar.	Water.	Gas.	Gas composition (calculated to undiluted gas.)						
					CO_2.	Illuminants.	CO.	CH_4.	C_2H_6.	H_2.	N_2.
At heating temperature of 700° C.											
	° C.	P. ct.	P. ct.	C. c.							
Connellsville, Pa	562	11.0	3.5	583	3.0	7.2	5.4	44.1	17.7	13.5	9.1
Zeigler, Ill	545	7.8	14.0	471	8.5	5.1	13.7	59.6	0	1.1	12.0
Sheridan, Wyo	580	8.2	18.5	1,020	28.8	3.7	20.0	18.6	6.8	15.1	7.0
Pocahontas, W. Va	599	4.2	1.9	675	1.9	4.4	3.9	44.4	16.1	28.5	.8
At heating temperature of 800° C.											
Connellsville, Pa	687	12.6	4.5	1,375	1.5	5.5	6.9	24.9	12.1	33.1	[a]16.0
Zeigler, Ill	680	9.3	13.9	1,251	3.8	3.8	16.0	27.7	6.1	33.7	[a]8.9
Sheridan, Wyo	.....	7.9	19.1	1,780	19.8	2.7	21.4	14.1	4.0	30.0	8.0
Pocahontas, W. Va	.....	6.5	2.4	1,590	1.2	3.4	4.8	24.4	11.6	43.2	11.4

[c] Includes small amount of air.

The differences in the ease with which various coals give off their smoke-producing constituents are strikingly shown by the accompanying diagram (fig. 40), in which all these volatile substances are grouped, the total percentages given off being represented by the vertical scale and the temperatures by the horizontal scale. The behavior of the Illinois coal at temperatures between 600 and 700° C. contrasts strongly with the progressive distillation of Connellsville coal, and the decline in production of volatile compounds at temperatures over 700° shown by Wyoming coal is notably different from the even increases shown by Illinois, Pocahontas, and Connellsville coals.

HORSEPOWER FROM DIFFERENT COALS.

The facts presented in Table 56 were obtained by averaging more than 200 tests on coals and lignites from 17 different States. All these fuels were hand fired under a Heine boiler. The furnace was set with flat grates, which were 26 inches from the U tile on the lower row of tubes, measured at about the center of the grate. Natural draft was used in nearly all the tests. The damper was usually set so as to get a draft of about 0.6 inch of water in the hood, this giving from 0.12 to 0.30 inch in the furnace, varying with the coal and the condition of the fire. On the assumption that the boilers at the average good plant are run at approximately the same efficiency as those at the government testing plant, the figures given in Table 56 for coal per boiler horsepower per hour may be used as a basis for an approximate determination of the total boiler horsepower at any plant by dividing the amount of coal used per hour by the figures in the table opposite the State from which the coal is supplied. For

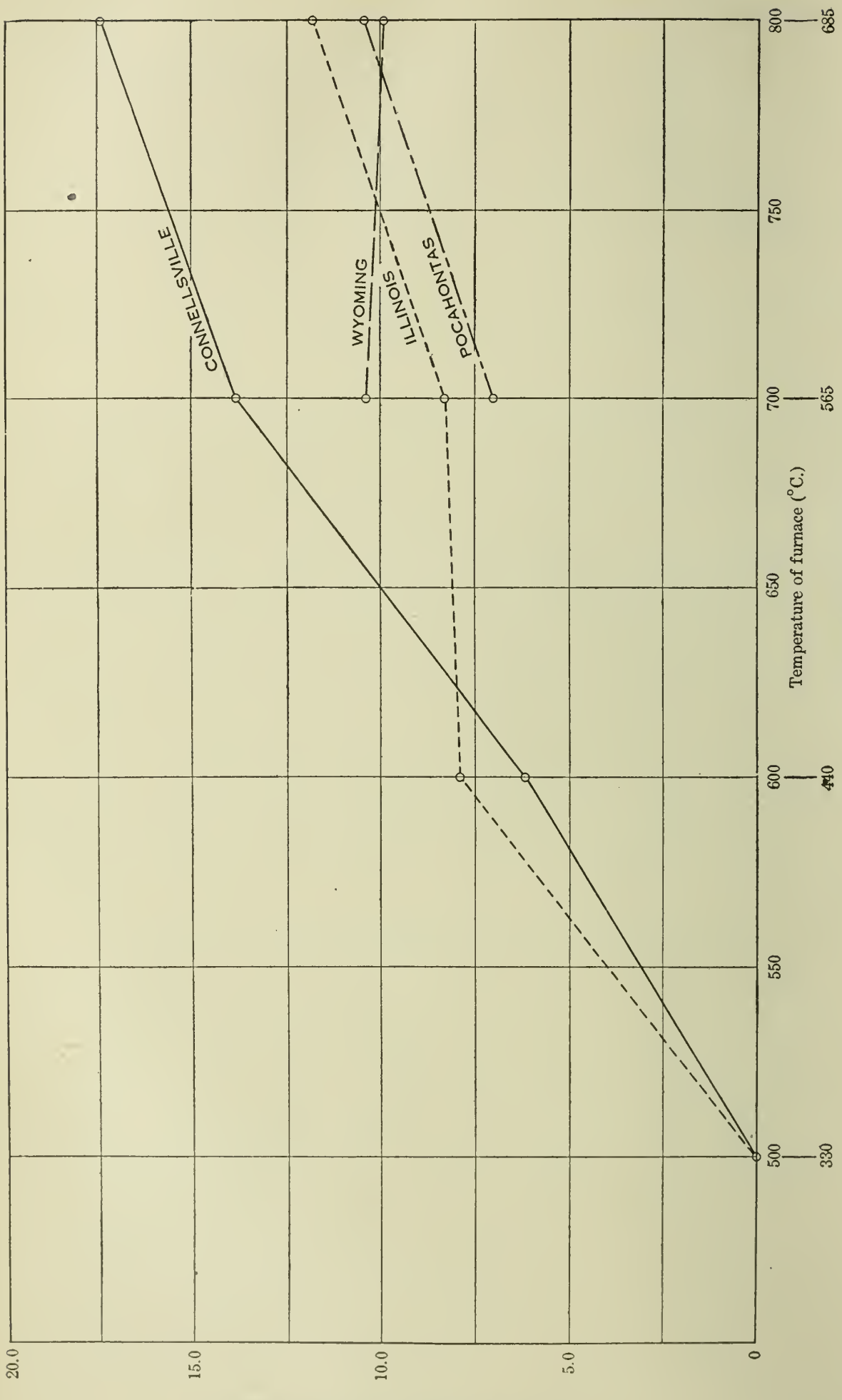


FIGURE 40.—Proportion of smoke-producing compounds given off at different temperatures by several coals.

instance, a consumption of 460 pounds of best Illinois coal per hour indicates that the total boiler horsepower developed would be about 100.

TABLE 56.—*Efficiency 72* and coal burned per boiler horsepower per hour.*

State.	Number of tests averaged.	Efficiency, 72*.	Coal burned per boiler horsepower per hour.	State.	Number of tests averaged.	Efficiency, 72*.	Coal burned per boiler horsepower per hour.
		Per cent.	*Pounds.*			*Per cent.*	*Pounds.*
Alabama	3	66	4.2	Kentucky	13	65	4.0
Arkansas	4	67	3.9	Maryland	3	66	3.8
Colorado (lignite)	1	61	6.0	Missouri	7	63	5.1
Illinois (best coal)	23	66	4.6	New Mexico	2	60	5.5
Illinois (fair and poor coal)	21	61	5.0	Ohio	26	64	4.2
Indiana	27	63	4.7	Pennsylvania	21	67	3.6
Indian Territory	4	64	4.5	Virginia	12	65	3.7
Iowa	5	61	5.5	West Virginia	36	67	3.6
Kansas	8	63	4.4	Wyoming (lignite)	8	59	6.1

CENTRAL HEATING STATIONS.

The possibility of reducing smoke in cities by the use of central heating plants was taken up as part of the general study of the smoke problem. There is no doubt that in winter the small heating plants, both in residences and in store buildings, contribute largely to the smoke nuisance. This is because the small plant is poorly designed for burning any but low-volatile fuels. When an attempt is made to burn the cheaper coals, such as large stations utilize, dense black smoke results, often lasting for several minutes after each coaling. Moreover, the plant is not large enough to warrant careful operation and the coal is fired in large quantities and at long intervals. To obviate the difficulties of combustion high-priced coal is burned, this being especially true in congested areas. It is evident that if for the heating plants of several buildings could be substituted a central station where a power-plant boiler of standard type could be installed, a correct furnace constructed, cheap fuel utilized, and the plant operated intelligently, much of the nuisance and discomfort from the small plants would be overcome.

The central heating plant is not a new thing; in fact some of the plants have been in operation for twenty to twenty-five years. Development in this direction has been very slow, however, until within the last five or six years, when the idea has received renewed attention.

The data presented in Table 57 were obtained by sending a circular letter to each of the central heating plants supposed to be in operation in the United States—150 in all. Of these, 77 responded, 57 giving the information as tabulated; twenty stated that they were out of business or inactive. The location of the 130 is given in the

statement below. The tabulated statistics may be taken as fairly representative of central heating plant conditions. It will be noted that the plants are most numerous in the States where coal is relatively cheap.

Location and number of central heating plants.

	Number of plants.		Number of plants.
Arkansas	1	Montana	1
Colorado	2	Missouri	4
Connecticut	1	New Hampshire	1
Georgia	1	New York	10
Idaho	1	North Dakota	2
Illinois	24	Ohio	24
Indiana	17	Pennsylvania	25
Kansas	1	Rhode Island	1
Massachusetts	2	Texas	1
Michigan	3	Washington	1
Minnesota	3	Wisconsin	4

TABLE 57.—*Details of operation of central heating plants.*

No.	Location of plant.	Purpose of plant.	Heating system.	Boilers.		Style of furnace.	Fuel.		Horsepower of engine.
				Character.	Horsepower.		Kind.	Cost per short ton.	
1	Colorado	Heat	Steam	Fire tube; Water tube	1,500; 2,200	Common	Lignite slack	$1.33	0
2	Illinois	Light, heat, and power	do	Water tube	4,200	Dutch oven	Bituminous slack	1.00	4,000
3	do	do	do	do	2,520	3 Green; 2 common	Bituminous screenings	1.50	3,150
4	do	do	do	do	1,800	Chain grates; Roney stokers	Bituminous pea and screenings	1.38	360
5	do	do	do	Fire and water tube	1,350	Common and chain grates	Bituminous screenings	1.85	1,700
6	do	do	do	Fire tube	600	Common	Run of mine and lump	1.30	400
7	do	Light and heat	do	do	450	do	Bituminous run of mine	1.70	120
8	do	Light, heat, and power	Steam and hot water.	Water tube	2,970	Chain grates	Bituminous screenings	.90	4,100
9	do	do	do	do	2,800	do	Run of mine and screenings		3,200
10	do	do	Hot water	do	1,100	Common	Bituminous screenings	1.20	1,250
11	do	do	do	do	400	do	Bituminous ¾-inch screenings	1.47	375
12	Indiana	do	do	do	1,800	Detroit and Roney stokers	Bituminous screenings	2.50	
13	do	Light and heat	do	do	1,720	Common	Bituminous slack	1.35	2,500
14	do	Light, heat, and power	do	do	1,000	do	Run of mine; screenings	1.75	570
15	do	do	do	Fire tube	400	do	Bituminous run of mine	1.12	
16	do	Light and heat	do	Water tube	800	1 common; 2 Roney stokers	Bituminous	2.61	515
17	do	Light, heat, and power	do	Fire and water tube	800	Common	Bituminous slack	2.20	880
18	Iowa	Light and heat	do	Water tube	800		Nut and run of mine	1.70	425
19	do	do	do	Fire tube	400	Common	Run of mine, nut steaming	3.00; 2.12	150
20	do	Light, heat, and power	do	do	300		Bituminous lump	1.95	250
21	do	Light and heat	Steam	Water tube	2,150	2 chain grates; 7 common	Bituminous screenings	1.70	2,800
22	Michigan	Light, heat, and power	do	Fire tube	600	Morrison suspension	Bituminous slack	2.90	400
23	Minnesota	do	do	Water tube	725	Common	⅔ anthracite, ⅓ bituminous	3.75	700
24	Missouri	do	do	Fire tube	900	Down draft	Bituminous lump	1.67	405
25	do	do	do	Water tube	900	2 down draft; 1 common	do	2.05	1,264
26	do	Heat	do	do	750	Common	Bituminous slack	1.75	0
27	do	Light, heat, and power	do	Fire tube	450	Down draft	Bituminous pea and nut	1.80	280
28	do	do	do	Fire and water tube	400	do	Bituminous lump	2.10	200
29	Montana	Light and heat	do	Water tube	1,500	American stoker	Bituminous slack	4.60	250
30	New York	Power and heat	do	do	16,000	Common	Anthracite	2.23	0
31	do	Heat	do	do	11,000	do	do	2.23	0
32	do	Light, heat, and power	do	do	2,368	do	Buckwheat	2.13	1,475
33	do	Light and heat	do	do	1,600	Murphy stoker	Bituminous	2.50	705
34	do	Heat	do	Fire tube	700		¾ anthracite, ¼ bituminous	1.74; 2.90	0
35	do	Power and heat	do	do	405	Murphy stoker	Screened nut	2.60	430
36	North Dakota	Light, heat, and power	do	Water tube	1,000	Common	⅔ anthracite, ⅓ bituminous	4.00	1,500
37	do	do	do	Fire tube	600		Lignite	2.00	600

TABLE 57.—*Details of operation of central heating plants*—Continued.

No.	Location of plant.	Purpose of plant.	Heating system.	Boilers.		Style of furnace.	Fuel.		Horsepower of engine.
				Character.	Horse-power.		Kind.	Cost per short ton.	
38	Ohio	Light, heat, and power	Hot water	Water tube	2,800	Dutch oven	Run of mine	$2.20	3,000
39	do	do	do	do	1,400		Run of mine, slack, natural gas	1.30	550
40	do	do	do	Water and fire tube	1,100	Common	Pea and slack	1.50	750
41	do	do	do	Water tube	950	do	Bituminous run of mine	2.25	1,000
42	do	Heat	Steam	Fire and water tube	1,200	6 common; 2 Murphy	Run of mine and slack	1.75	0
43	Pennsylvania	do	do	Fire tube	1,600		Anthracite buckwheat	1.50	0
44	do	do	do		1,700	Common	Anthracite and bituminous	2.28	0
45	do	Power and heat	do	Fire and water tube	1,550	8 underfeed; 1 common	Bituminous	2.75	
46	do	Light, heat, and power	do	Fire tube	1,500	Roney stokers	Slack	1.00	1,200
47	do	do	do	Fire and water tube	1,400	Common	Bituminous	2.59	1,050
48	do	Heat	do	Fire tube	1,200		do	1.03	0
49	do	do	do	do	1,000	Common	Anthracite rice and buckwheat	1.14	0
50	do	Light, heat, and power	do	Water tube	950	Murphy stokers	Anthracite rice and bituminous run of mine	2.63	1,050
51	do	Heat	do	Fire tube	900	Common	Anthracite	1.03	0
52	do	do	do	3 fire tubes; 1 water tube	725	Wilkinson stokers	Bituminous	2.77	0
53	do	Light, heat, and power	do	Water tube	600	Common	Run of mine	1.38	300
54	do	Heat	do	Fire tubes	600	do	Bituminous run of mine	1.37	0
55	Rhode Island	Light, heat, and power	do	Water tube	3,315	do	Bituminous	3.75	4,250
56	Wisconsin	do	Hot water	Fire and water tube	600	do	Bituminous screenings	1.90	800
57	do	Light and heat	do	Water tube	600	do	Bituminous run of mine	2.50	800

TABLE 57.—*Details of operation of central heating plants*—Continued.

No.	Location of plant.	Live steam used (per cent).	Mains leading from plants.		Pressure (pounds).		Greatest distance heat is conveyed (feet).	Total length of heating mains (feet).	Insulation.	Radiation (square feet).	
			Number.	Size (inches).	On mains at plant.	Drop in main.				Direct.	Indirect.
1	Colorado	100			50	42	7,550	38,173	Lapped with asbestos inside 4-inch wood log		Very little.
2	Illinois		1	8	15	12	3,960	10,560	Tin, asbestos, and 4-inch wood log	200,000	None.
			1	12							
3	do		1	20	20	15	7,200	14,784	4-inch wood log		Very little.
4	do	33	1	10	10	6	2,000	4,000	1-inch magnesia pipe covering		
			1	6							
5	do	0	1	5	3–6	2	3,960	7,920	1-inch felt and wooden box		None.
			1	8						35,000	
6	do		1	8	6–15	1–3	2,640	2,640	6-inch wood logs	2,000	None.
7	do	0	1	8	2	¼	1,300	4,000	7-inch hemlock and hair		
8	do	50	*a* 1	16	*a* 8–*b* 50		5,280	*a* 15,840	Air chambers and sawdust	*a* 180,000	
			b 1	12				*b* 31,680		*b* 270,000	
9	do		*a* 1	12	6	6	*a* 3,000		Magnesia and oil shavings	75,000 x 2	Very little.
			b 1	8			*b* 6,600				
10	do	65	6	7	60	10	7,920	58,080	3-inch wood box	100,000	None.
11	do	0	1	10	88	9	2,640	17,500	2-inch sawdust and lime		Do.
12	Indiana	0	1	20	30				Boxing; mineral wool	400,000	Do.
13	do		2	12	48	20	3,960	10,560	3-inch wood covering	120,000	Do.
14	do		2	10	70	40	4,500	34,000	4-inch wood and hair felt	130,000	Do.
15	do		1	7	40	10	5,280	15,840	4-inch wood logs	60,000	Very little.
			1	6							
16	do	16	*c* 1	12	50	25	1,500	12,000	5-inch hemlock boards and air space	70,000	None.
17	do	15	*c* 1	6	60	15	5,000	18,480	5-inch air space; boards and shavings, and tarred felt	115,000	
			c 1	7							
18	Iowa	33⅓	1	8	45–60	10–15	3,520		Hemlock covering, with two air spaces	85,000	None.
19	do	75	*c* 1	7	51	8	3,000	*d* 8,800	3¾-inch wood	61,000	Do.
20	do	(*e*)	1	5	30		2,000	4,000	Wood	20,000	Do.
21	do		1	12	17	15	4,500	12,000	4-inch wood logs	138,000	
22	Michigan	66	2	10	3	¼	1,300	4,000	2-inch 85 per cent magnesia	50,000	None.
23	Minnesota	(*f*)	1	8	5	0	1,600	3,960	3-inch wood logs	30,000	
24	Missouri		1	16	3		1,072	1,460	1-inch paper; air cell	11,481	150,460
25	do	(*g*)	2	12	¾	0	400	700	1-inch 85 per cent magnesia	4,900	None.
26	do	100	1	10	5	1	4,600	7,920	4-inch kiln-dried pine; wood log	83,082	
27	do		7	6	1½	0	130	600	⅞-inch magnesia	33,000	None.
28	do	50	1	10	5½	1	400	700	1-inch asbestos	38,267	Do.
29	Montana		8	12	10	½	2,000	4,000	1-inch asbestos; sponge felt	70,000	Do.
30	New York	100	3	15	95	10	3,200	29,040	1-inch air space; 4-inch mineral wool inside conduit		

a Steam. *b* Hot water. *c* Pair. *d* Double pipe. *e* Very little. *f* 75,000 pounds per day. *g* 146,000 pounds per day.

TABLE 57.—*Details of operation of central heating plants*—Continued.

No.	Location of plant.	Live steam used (per cent).	Mains leading from plants.		Pressure (pounds).		Greatest distance heat is conveyed (feet).	Total length of heating mains (feet).	Insulation.	Radiation (square feet).	
			Number.	Size (inches).	On mains at plant.	Drop in main.				Direct.	Indirect.
31	New York	100	1 1	15 24	55	5–15	7,500	58,080	1-inch air space; 4-inch mineral wool inside conduit	1,100,000	
32	do		1 1	15 12	5		922	4,070	1½-inch 85 per cent magnesia	65,430	None.
33	do	70	4	14	4½	3½	3,960	31,680	4-inch kiln-dried sectional white pine, wood logs	124,000	
34	do	100	1	10	20	5	5,280	7,000	Tin, asbestos, 4-inch wood logs		Very little.
35	do	100±	1	8	5	0	1,200		4-inch wood log		
36	North Dakota	50	1	10	7½		1,500	3,000	Tin, asbestos, 4-inch wood logs	50,000	None.
37	do		1 1	12 8			1,000	2,000	Tin, asbestos, and wood logs		
38	Ohio	0	2	12	45	30	11,880	47,520	5-inch wooden box; air space; oil shavings	160,000	None.
39	do	0	2	8	70		6,600	21,120	Wood shavings and mineral wool	110,000	Do.
40	do	20	2	8	30	6	5,500	10,560	5-inch wood; air space; box	80,000	Do.
41	do	(a)	b 2		40	15	3,520	7,000	2-inch wood covering	30,000	Do.
42	do	100	1	14	½–6	¾	3,178	5,492	4-inch tin-lined wood casing		
43	Pennsylvania	(c)	12	3	50	47	5,280	46,200	Tin-lined 4-inch wood log		
44	do	100	10	3	5–20		5,280	11,880	3-inch wood log	42,000	
45	do	100	1 2	10 6	12–25	7	3,917	28,945	Asbestos and 4-inch wood logs	29,785	162,182
46	do		1	14	2–6		4,000	13,200	Tin, asbestos, 4-inch wood logs	50,400	5,600
47	do	100	1	12	15	11		9,500	4-inch asbestos and wood logs		
48	do	100	1	8	20		3,960	3,960	⅝-inch asbestos		
49	do	100	1	10	30	25	6,000	6,000	2-inch asbestos and wood log		Very little.
50	do	50	1	12	4	2¼	3,550	8,777	Tin, asbestos, 4-inch wood logs	88,611	None.
51	do	100	1	10	50–70	35–40	5,000	7,200	4-inch wood log	70,000	
52	do	100	1 1	8 12	10–20	5–15	4,620	17,911	3-inch concrete duct; 3-inch and 4-inch wood log; 3-inch air space.	57,324	60,909
53	do		1	8	6	(a)	3,960	7,920	1-inch wood		None.
54	do	100	1	8	15–40	10–35	2,640	10,560	Asbestos and 4-inch wood logs	45,000	
55	Rhode Island	100	1	8	14	5	2,042	5,285	Tin, asbestos, 4-inch wood logs		Very little.
56	Wisconsin	90	1	4	55	15	2,000	4,000	1½-inch wood log	10,000	None.
57	do	0	2	8	60	40	7,920	31,680	3-inch hemlock boxing and air space	70,658	Do.

a Very little. b Pair. c Nearly 100.

TABLE 57.—*Details of operation of central heating plants*—Continued.

No.	Location of plant.	Space in buildings (cubic feet).	Average price of heating.		Average cost per year for repairs on mains, tunnels, and insulation.	Years in operation.	Remarks.
			Per square foot.	Per 1,000 pounds of water.			
1	Colorado	700,000	$0.65		$1,500	26	Condensation loss, 12 per cent. Price to large dealers, $2 per 1,000 cubic feet of contents.
2	Illinois	1,200,000	.24			12	$4 per 1,000 cubic feet of contents.
3	do			$0.45	None.	3	Live steam one-tenth of season.
4	do				Very small.		Radiation direct and indirect.
5	do					7	Direct system.
6	do		.25		$100	5	Profitable when heat is furnished as a secondary product.
7	do		.28		None.	2	
8	do	a 9,000,000 b 9,450,000	a .25 b .15			a 17 b 5	Do.
9	do		a .22½ b .75½			6½	Would advise concentration of mains.
10	do		.15		10 per cent.	6	Would advise use of larger mains; also concentration of territory heated. Insulation could be improved.
11	do		.20			7	
12	Indiana		.20			5	
13	do		.18		$400	5	Profitable when heat is furnished as a secondary product.
14	do		.15½			5	Charge too low for successful operation.
15	do		.12½			7	Do.
16	do		.15			5	Condensation loss, 5 per cent.
17	do		.17		5 per cent.	10	Radiation mostly direct. Heat should be automatically regulated.
18	Iowa		.18		$300	7	Mains should not extend too far from plant.
19	do		.20		$100	6	
20	do		.15			5	Profitable when exhaust steam is used for heating.
21	do	10,000,000		.50	$359	15	Radiation mostly direct.
22	Michigan	2,389,900			$150	3	
23	Minnesota			.60	$6	8	Radiation direct and indirect. Condensation loss, 6 per cent.
24	Missouri	3,771,515				5	
25	do	3,634,365			$25	4	
26	do	5,391,295		.56	0	7	Radiation direct and indirect. Condensation loss 1 per cent.
27	do	1,650,000			0	15	
28	do	2,204,612	.25		0	10	Mains should not extend too far from plant.
29	Montana	7,777,000	.60		Very small.	7	88,000,000 pounds steam sold per year.
30	New York			.50		25	Over one-half of the steam is sold for power purposes.
31	do	100,000,000		.50			
32	do	15,500,000			Small.	10	Profitable when exhaust steam is used.
33	do	10,000,000		.42½	$175	28	Condensation loss, 3 to 6 per cent. Radiation both direct and indirect.

a Steam. b Hot water.

TABLE 57.—*Details of operation of central heating plants*—Continued.

No.	Location of plant.	Space in buildings (cubic feet).	Average price of heating.		Average cost per year for repairs on mains, tunnels, and insulation.	Years in operation.	Remarks.
			Per square foot.	Per 1,000 pounds of water.			
34	New York	7,000,000			3 per cent.	10	Condensation loss, 5 to 12 per cent. Radiation both direct and indirect. Business rate 4; residence rate $4.50 per 1,000 cubic feet of contents.
35	do			$0.48	Very small.	6	
36	North Dakota	5,000,000		.60	0	7	Condensation loss, 5 per cent on heavy load, to 50 per cent on light load.
37	do			.40		6	Profitable when exhaust steam is used.
38	Ohio		$0.15		0	3	
39	do		.15		Very small.	5	Natural gas 9 cents per 1,000 cubic feet.
40	do		.20		$300	7	
41	do	1,200,000	.17½		0	4	
42	do	10,000,000		.50	0	7	
43	Pennsylvania	26,000,000			$2,000	10	$4.50 per 1,000 cubic feet of contents; should have larger mains.
44	do	10,000,000			$0.41 per 1,000 cubic feet of space heated.	19	$4.43 per 1,000 cubic feet of contents; steam should be metered.
45	do	9,129,251			$300	14	Radiation should be direct and steam should be metered. Present price of heating based on cubic contents.
46	do	3,360,000	.25		$250	5	
47	do	9,000,000			$702	9	Radiation both direct and indirect. Profitable when exhaust steam is used for heating.
48	do				$500	20	$5.45 per 1,000 cubic feet of contents.
49	do					20	$4.50 per 1,000 cubic feet of contents. Insulation could be improved. Should run with higher steam pressure at plant.
50	do			.40	0	5	Condensation loss, 9 per cent. Profitable when steam is sold at 60 cents per 1,000 pounds.
51	do	5,000,000			$700	19	Radiation about 5 per cent. $5 per 1,000 cubic feet of contents.
52	do	5,093,161			$500	14	$6 per 1,000 cubic feet of contents. Radiation should be direct and service should be metered.
53	do		.34		$100	10	
54	do		.33⅓			24	Very little indirect radiation. Mains should not extend too far from plant.
55	Rhode Island			.66		6	Condensation loss, 4 to 15 per cent.
56	Wisconsin		.25			6	Profitable when exhaust steam is used.
57	do		.20			8	Insulation could be improved. Mains should not extend too far from plant. Profitable when exhaust steam is used.

Of the 57 plants included in Table 57 only 12 were operating for the express purpose of central heating. The remaining 45 were supplying either light and heat, power and heat, or power, light, and heat. Steam heat is furnished by 38 plants, hot water by 17, and a combination of steam and hot water by 2. The plants which have been installed in the last five or six years show about an equal proportion of steam and hot-water heating. The plants range in size from 300 to 16,000 horsepower; only 25 per cent are of 600 horsepower or less. Sixteen of the plants have mechanical stokers. The price of coal ranges from $4.60 per short ton in Montana to 90 cents in Illinois, the average cost from all the plants being $2.05 per short ton. Both direct and indirect radiation are used, but by far the greater proportion is direct. The greatest distance to which heat is sent from the station varies considerably, but a reasonable distance seems to be about 4,000 to 5,000 feet.

Payment for the use of steam is made in two ways—(1) at a flat rate, based on square feet of radiating surface installed or on 1,000 cubic feet of contents heated, or (2) at a meter rate, based on 1,000 pounds of condensed steam. The price paid per square foot of radiating surface averaged 33⅓ cents, and varied from 22½ to 65 cents. The plants selling on a basis of 1,000 cubic feet of contents charged an average of $4.46, the price varying from $2 to $6. On the basis of 1,000 pounds of condensed steam the payments averaged 50½ cents, ranging from 40 to 66 cents. One plant that sold heat on this basis for 40 cents intimated that such a rate was not profitable.

The hot-water plants sold heat only on the basis of square feet of radiating surface installed, the average rate being 17½ cents and the range from 12½ to 25 cents per square foot. Two plants, one selling at 12½ and the other at 15½ cents, claimed that their prices were too low for successful operation.

A comparison of the prices charged by central stations, as given in Table 57, with the cost of fuel only for a house-heating boiler, as published in Bulletin 366,[a] shows that in many cases the cost of producing heat on the premises equals the price charged by the central station. When heat is purchased the customer avoids the annoyance of having to supervise the operation of the heating plant, as well as the dust resulting from the delivery of fuel and the removal of ashes. Some allowance should also be made for the space that would be occupied by the heater and for the expense necessary to install and keep a boiler in repair.

The following suggestions have been made by the managers of the plants and are worthy of consideration:

Heat from a central plant should be, as largely as possible, a secondary product.

[a] Randall, D. T., Tests of coal and briquets as fuel for house-heating boilers: Bull. U. S. Geol. Survey No. 366, 1908, p. 39.

Heating mains should be concentrated and should not extend too far from the station.

Direct radiation should be installed.

Mains should be of sufficient size to avoid the necessity of high pressure at the station.

Heat should be under automatic control.

The flat rate is not a successful basis for payment; the service should be metered.

GENERAL CONCLUSIONS ON SMOKE ABATEMENT.

Some general conclusions from the facts set forth in this volume are as follows:

The flame and the distilled gases should not be allowed to come into contact with the boiler surfaces until combustion is complete.

Fire-brick furnaces of sufficient length and a continuous or nearly continuous supply of coal and air to the fire make it possible to burn most coals efficiently and without smoke.

Coals containing a large percentage of tar and heavy hydrocarbons are difficult to burn without smoke and require special furnaces and more than ordinary care in firing.

Briquets are suitable for use under power-plant conditions when burned in a reasonably good furnace at the temperatures at which such furnaces are usually operated. In such furnaces briquets generally give better results than the same coal burned raw.

In ordinary boiler furnaces only coals high in fixed carbon can be burned without smoke, except by expert firemen using more than ordinary care in firing.

Combinations of boiler-room equipment suitable for nearly all power-plant conditions can be selected, and can be operated without objectionable smoke when reasonable care is exercised.

Of the existing plants some can be remodeled to advantage. Others can not, but must continue to burn coals high in fixed carbon or to burn other coals with inefficient results, accompanied by more or less annoyance from smoke. In these cases a new, well-designed plant is the only solution of the difficulty.

Large plants are for obvious reasons usually operated more economically than small ones, and the increasing growth of central plants offers a solution of the problem of procuring heat and power at a reasonable price and without annoyance from smoke.

The increasing use of coke from by-product coke plants in sections where soft coal was previously used, the use of gas for domestic purposes, and the purchase of heat from a central plant in business and residence sections all have their influence in making possible a clean and comfortable city.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
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BULLETIN 374

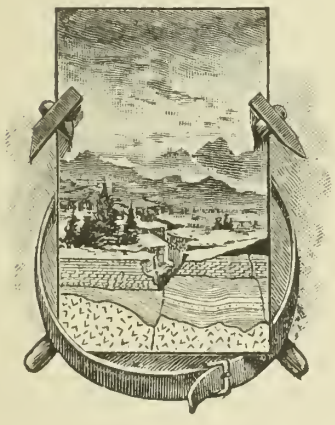
MINERAL RESOURCES

OF THE

KOTSINA-CHITINA REGION, ALASKA

BY

FRED H. MOFFIT AND A. G. MADDREN



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PREFACE.

By Alfred H. Brooks.

Native copper from the district described in this volume is the first mineral reported from Alaska. Steller, the naturalist who accompanied Bering on his voyage of discovery in 1741, noted the use of copper knives among the natives of Kayak Island. This copper undoubtedly came from the Chitina-Kotsina belt. Among the Alaskan natives the use of copper was widespread, for it was the only metal utilized by them, but apparently the century of occupation by the Russians passed without any search on their part for the locality from which the supply was derived. The only attempt made by the Russians to explore the Copper River (Serebranikof, 1847) resulted in the massacre of the whole party by the Indians.

The first successful explorations were made by Allen (1885) and by Schwatka and Hayes (1891), and the first systematic surveys were carried out by Schrader of the United States Geological Survey and his associates in 1900.

It is part of the Survey's plan for the investigation of the mineral resources of Alaska to keep the work abreast of the mining developments in each district so far as the means available will permit. As a great deal of prospecting, which has developed many new facts in regard to the occurrence of ore, has been done in the Chitina Valley since 1900, and as the valley has become a focal point of interest to those who are considering railway construction into the interior, a reexamination of the copper belt seemed to be necessary. A new report was, furthermore, justified by the fact that the edition of Schrader and Spencer's report, published in 1900, is now out of print.

The portion of the present volume which treats of the general geology is to be regarded as a revised edition of that report, which has been of incalculable value as a guide to the prospectors. The geologic map which resulted from Schrader and Spencer's very hasty reconnaissance has stood the test of seven years of active prospecting, and the authors of the present report, Messrs. Moffit and Maddren, after a careful reexamination of this district, have made but few changes.

The topographic map accompanying this report, based on the surveys of Gerdine and Witherspoon in 1900 and 1902, and of Hamilton and Hill in 1905, has been entirely redrawn, with the aid of the data afforded by several railway surveys and of the work of the Coast and Geodetic Survey along the seaboard.

The description of the occurrence of mineral deposits is entirely by Moffit and Maddren, but their work was much aided by the earlier studies of Schrader, Spencer, and Mendenhall.

This second report on the copper belt can be regarded as only another step toward the solution of the many problems connected with the economic geology of the region. Detailed surveys will be necessary before the problems can be submitted to an ultimate analysis. For this reason there is in preparation a detailed topographic map of the eastern end of the field, in which the deepest mining has been done and which seems to afford the best opportunity for solving the geologic problems. The detailed geology of this area will be studied as soon as means will permit, for it is believed that such a study will throw light on the occurrence of copper throughout the field.

MINERAL RESOURCES OF THE KOTSINA-CHITINA REGION, ALASKA.

By Fred H. Moffit and A. G. Maddren.

INTRODUCTION.

The increased demand for copper and its prevailing high price, due chiefly to remarkable advances in the use of electric power, have, during the last few years, attracted much attention to the copper deposits of Alaska. Copper has been found in many parts of Alaska, but at present only three regions or districts give promise of making any important contribution to the copper market. These regions are Prince of Wales Island in southeastern Alaska, Prince William Sound, and the Copper River–Chitina River region. The first two regions have produced copper for several years, as their mines are situated near the ocean and enjoy cheaper transportation facilities, but the interior region is still in the prospecting stage and will remain so till a better and more economical means of handling supplies and ore is provided.

The investigations of the Geological Survey in the interior copper region during 1907 were carried on in its southern portion, which includes Kotsina River and most of the northern side of Chitina River valley. This work was a continuation of the investigations of Schrader and Spencer in 1900, and with the results of their study in hand greater headway was made than would otherwise have been possible. The work consisted chiefly of visits to the various copper prospects and investigations of the occurrence of copper, but the study of the regional geology was continued, so far as it could advantageously be carried on. A second object of the expedition was an investigation of the Nizina gold placers. The party landed at Valdez in the middle of June, but, owing to the necessity of making double trips with the summer's supplies and to other delays, field work was not begun till July 10, when Elliott Creek was reached. From that time till the last of September it was continued with little interruption, so that nearly eighty days were included in the

field season, of which much the greater part was devoted to a study of the copper deposits.

Exploration in the Chitina River valley was begun in 1885, when Lieut. (now Maj.) Henry T. Allen, in the course of a remarkable journey from Prince William Sound to St. Michael, during which he traversed portions of the valleys of Copper, Tanana, Koyukuk, and Yukon rivers, ascended Chitina River on the ice from Taral to Nikolai House near the mouth of Dan Creek. Lieutenant Allen made a reconnaissance route map of the region through which he went and in his report mentioned the occurrence of copper in the vicinity of Chitistone River, or Nizina River, as it is now called.

In 1891 Lieut. Frederick Schwatka, U. S. A., and C. Willard Hayes, of the Geological Survey, both acting in a private capacity, entered Chitina River valley by way of Skolai Pass. They descended Nizina River nearly to Dan Creek on foot, but after building a canvas boat continued their journey down Nizina, Chitina, and Copper rivers to the coast. They also made a reconnaissance route map of their traverse. In 1899 a party in charge of Oscar Rohn explored the region south and east of Mount Wrangell. This party was a detachment from the military exploration in charge of Capt. W. R. Abercombie.

In 1900 a geologic and topographic reconnaissance of the Chitina and Hanagita valleys and of the lower Copper River was made under the direction of Frank C. Schrader, of the Geological Survey. The topographic map was made by T. G. Gerdine and D. C. Witherspoon. The geologic investigations were carried on by F. C. Schrader and Arthur C. Spencer. This work, although hastily done, owing to the difficulties of travel and the necessity of covering the greatest possible area in the time available, has nevertheless been of very great value to prospectors of the region.

Two years later, in 1902, Walter C. Mendenhall, of the Geological Survey, during an investigation of the geology and mineral resources of the central Copper River region, visited the copper prospects of Kotsina River and Elliott Creek.

A list of the publications resulting from the work of these expeditions is here given:

ALLEN, Lieut. Henry T. Report of an expedition to the Copper, Tanana, and Koyukuk rivers, in the Territory of Alaska, in the year 1885. Washington, Government Printing Office, 1887.

HAYES, C. Willard. An expedition through the Yukon District: National Geographic Magazine, vol. 4, 1892, pp. 117–162.

ROHN, Oscar. A reconnaissance of the Chitina River and the Skolai Mountains: Twenty-first Ann. Rept., U. S. Geol. Survey, pt. 2, 1900, pp. 393–440.

SCHRADER, Frank Charles, and SPENCER, Arthur Coe. The geology and mineral resources of a portion of the Copper River district, Alaska. Special publication of the U. S. Geological Survey, 1903.

MENDENHALL, Walter C., and SCHRADER, Frank C. The mineral resources of the Mount Wrangell district, Alaska: Prof. Paper U. S. Geol. Survey No. 15, 1903.

MENDENHALL, Walter C. Geology of the central Copper River region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1905.

GEOGRAPHY AND HISTORY.

GEOGRAPHIC POSITION.

The Kotsina-Chitina region, as represented on the topographic and geologic map made under Schrader's direction in 1900 (Pl. II), is included in a quadrangle bounded by parallels 61° and 62° north latitude and meridians 142° and 145° west longitude. This map does not, however, include all the area surveyed that year, since the trail from Valdez to Copper River, the lower Copper River, and the upper portion of Tana River are omitted (Pl. I).

Copper River is joined about 100 miles from its mouth by its large eastern branch, Chitina River, whose general course is nearly west-northwest. On ascending the main branch of the Copper it is found that the river first bears to the northwest, then swings northeast, and finally southeast. Thus the two branches of Copper River, the Chitina and the upper Copper, nearly surround the Wrangell Mountains. The area included between these two streams and the heads of White, Chisana (or "Shusana"), and Nabesna rivers is generally referred to as the Copper River copper region. It is divided into a northern and a southern district by the Wrangell and Skolai mountains, whose ice-covered ridges form an almost impassable barrier between them. This paper deals with the southern district only.

The Wrangell Mountains are a somewhat detached or partly isolated mass, bounded on the north, west, and south by valleys whose trend is west-northwest and east-southeast. To the southeast they merge into the Skolai Mountains, and these in turn unite with the St. Elias Range. Their summits rise to altitudes ranging from 8,000 to more than 16,000 feet, and reach their greatest elevation in such peaks as Regal Mountain (13,400 feet), Mount Blackburn (16,140 feet), and Mount Wrangell (14,005 feet), all of which are visible from Chitina Valley. Mount Drum (12,000 feet) and Mount Sanford (16,200 feet) are conspicuous in upper Copper River valley, but are hidden on the south by the other peaks mentioned.

The lofty summits of these mountains and the ridges that join them are the gathering places for snows that feed the numerous glaciers that creep down their sides and out into the valleys at their feet. These snow fields and glaciers are the sources of nearly all the large tributaries of Chitina River. A glance at the map (Pl. I) will show the great difference between the quantities of water supplied to the river from the two sides of its drainage basin.

Nizina, Lakina, Gilahina, and Kuskulana rivers are the largest northern tributaries of the Chitina. Kotsina River, which joins the Copper 2 miles above the Chitina's mouth, and is therefore not a tributary of the latter stream, is also fed by the glaciers. The largest southern tributaries to Chitina River are Tana River, heading in a glacier of the mountains between Chitina Valley and the coast, and Chakina and Tebay rivers, draining Hanagita Valley.

The Chitina Valley floor is a broad, gravel-covered, lake-dotted flat land expanse with a maximum width of at least 10 miles, whose surface is broken here and there by low round-topped hills and by deep canyons of streams which cross it. Chitina River, in the lower 50 or 60 miles of its course, has cut a deep broad channel in the valley floor, and for most of that distance it flows close to the foot of the mountain slopes on the south. The flood plain in places, particularly along the river's lower course, reaches a width of 1 mile, and is bounded on one or on both sides by banks—in some places gravel, in other places hard rock—which gradually decrease in height downstream, but which have an average height of between 100 and 200 feet. Over this gravel flood plain the river flows in numerous branching subchannels, whose positions are constantly changing, and are particularly unstable at the time of spring floods, so that those who follow them one year may find them entirely different the next year. The current is swift, rarely less than 6 or 7 miles per hour.

About 45 miles above its mouth Chitina River forks, the southern branch retaining the name Chitina, and the northern being known as Nizina River. The northern branch is almost as large as the southern and drains nearly half of the copper-bearing region. For 2 or 3 miles above its mouth Nizina River flows through a deep, narrow, winding box canyon, cut through solid rock. Above this for 8 or 10 miles the canyon is much less pronounced, the walls in places being steep gravel banks instead of rock cliffs. Still farther upstream the canyon gives way to a wide gravel flood plain, which gradually narrows and leads into the open glaciated mountain valley of the upper river. Each of the important headwater tributaries of Nizina River, except Dan and Chititu creeks, has a glacial origin.

This general description might be applied with slight modification to all the large northern tributaries of Chitina River, and to Kotsina River also. All except Gilahina River spring from glacial sources, traverse broad, gravel-floored glaciated valleys in the mountain district, and finally cross the Chitina Valley in deep canyons before joining the main river.

They drain an area of exceedingly rugged topography, whose sharp outlines are softened only in the vicinity of Young Creek. Between Hanagita Valley and Chitina River the mountains are lower and less

rugged, and lack the snow fields and glaciers so commonly seen in the Wrangell Mountains. The streams are smaller, and descend through steep gulches to the river. South of Hanagita Valley are other lofty snow-capped sierras, forming part of the Coast Range, but they are beyond the limits of the area under consideration.

TRAILS AND ROUTES.

The Kotsina-Chitina region may be reached from Valdez in summer by the Government trail between Valdez and Eagle, and in winter either by the same route or by way of Tasnuna and Copper rivers. One may also enter the region from Eagle or Fairbanks by the Government trail, but these routes are used only by those already in the interior. Skolai Pass is now frequently crossed by those going from Nizina River to the head of the White, or in the opposite direction, and it is reported that two prospectors went from Yaktag on the coast to Chitina River by way of the Tana River glacier. Neither of these, however, is a practicable route of travel. Up to the present Valdez has been the coast point from which all supplies were taken into the Copper River region. The Government trail is the route always followed in summer, and is the one usually chosen in winter. Leaving Valdez the main trail is followed till Tonsina River bridge is crossed. From there a second trail leads eastward about 25 miles along the high bluff north of Tonsina River to Copper River. The total distance from Valdez to Copper River by this route is approximately 100 miles.

Copper River is crossed at a point 2 miles above the mouth of Tonsina River. An Indian named Billum has a ferry license and transfers travelers with their baggage in two small boats. Horses must swim the river. After crossing Copper River the trail follows the east bank 6 miles to Billum's lower cabin and then, leaving the river, proceeds northeast 3 miles to Horse Creek. At Horse Creek it divides, one branch leading northeast to upper Kotsina River and Elliott Creek, the other southeast to the copper camps and gold placers of Chitina Valley.

The Tasnuna-Copper River route from Valdez to Chitina River can be used only when the river is frozen over, for the trail is on the ice all the way after leaving Tasnuna River. Supplies for the Chitina Valley leave Copper River on reaching Chitina River and are carried up that stream. Those destined for Kotsina River and Elliott Creek continue up the Copper to the summer trail at Billum's lower cabin. The great advantage of the Tasnuna River route is the saving of time under favorable conditions by the possibility of hauling heavy loads. A snow plow is used to break a trail, over

which the freight is hauled on heavy bobs in place of the narrow double-ended sleds employed elsewhere. This advantage may be entirely offset by the loss of time due to the fearful winds which sweep down the river and prevent any travel for days at a time. The Government trail has the advantage of being kept open all winter, since it is the mail route and is traveled regularly. Its chief difficulty lies in the crossing of Thomson Pass.

Returning now to the Kotsina-Chitina area: Of the two trails leading from Horse Creek—the Kotsina trail and the Chitina Valley trail—the Kotsina trail proceeds northeastward to Willow Creek, a small tributary of Kotsina River, where a branch trail, after the Hubbard-Elliott bridge over the Kotsina has been crossed, leads over a steep spur of Hubbard Peak to Elliott Creek. The main trail continues along the right, or west and north, bank of Kotsina River into Kotsina Valley. The stream issuing from Long Glacier is crossed on ice at the glacier's lower end; and bridges over Kluvesna River and over Kotsina River near Rock Creek obviate most of the difficulties and dangers formerly offered by these streams.

The Chitina Valley trail runs southeastward from Horse Creek, and reaches Kotsina River at a point 8 miles below Willow Creek. A bridge recently built by the Government at this place does away with another dangerous ford. From the government bridge the trail continues eastward along the Wrangell Mountain foothills, crossing Kuskulana River 3 miles below the glacier, and reaching Chokosna River and the Lakina by way of Kuskulana Pass. Ascending Fohlin Creek, it proceeds by way of Bear Creek and Fourth of July Creek to Kennicott Glacier and Kennicott River, which is crossed on the glacier ice. A good trail has been built from the glacier's lower end to the Bonanza property. Another trail ascends McCarthy Creek 4 miles and, crossing the ridge known as Sourdough Hill, lands one on Nizina River at a place from which Chititu Creek, Dan Creek, and Chitistone River are reached with ease when once the Nizina has been forded. There are no bridges east of Kotsina River, and the streams being of glacial origin are very cold and subject to great and rapid changes in the quantity of water carried, but the only ones likely to cause trouble are the Kuskulana, Lakina, and Nizina.

Most prospectors leaving the Nizina country descend Chitina and Copper rivers in small boats, either leaving the Copper at Tasnuna River and going overland to Valdez or following the river to the coast and landing in Eyak or Orca. Several days' work is required for whipsawing lumber and building a boat, but even then the river trip is much easier and quicker than the trail. The trip from the mouth of Young Creek to Tasnuna River, over 115 miles,

has been made in less than twenty running hours. A skillful boatman would meet with little or no difficulty on the Copper or Chitina, but the canyon at the lower end of Nizina River is dangerous, particularly at low water, and a number of persons have been drowned in trying to run through it.

In July, 1907, a small steamboat called the *Chitina* made her first trip from Tasnuna River to Copper Center, on Copper River, and to the Nizina, on Chitina River. Material for her construction was carried over the snow from Valdez during the previous winter, and she was completed early in July, but after the trip up the river was hauled out on the bank for the winter. She draws very little water, but will probably be unable to run after the middle of summer, because the Chitina is much lower in the fall than during the spring and early summer. She can not descend Copper River farther than Abercrombie Rapids, 25 miles below Tasnuna River, and any freight she may carry up the river must be delivered to her either at the rapids or at Tasnuna River.

The mineral resources of the Copper River region will remain undeveloped until a more reliable and economical means of transporting freight to and from it has been provided, and since Copper River can never become a highway of communication, such as the Yukon is for the northern country, no important copper production can be expected till a railroad has been constructed to connect the copper-bearing area with a coast point. On the other hand, it is hardly possible that such a road would be profitable until the region reaches a stable productive stage. The success of the one then appears to depend on the establishment of the other, and it is not strange that the future of each has so far been more or less in doubt.

There has been no lack of projects for the building of a road. Some have even been carried to a point where their accomplishment seemed almost assured and yet have fallen through. Nevertheless, it is probable that within a few years there will be railroad communication between the coast and the lower limit of steamboat navigation on Copper River.

Four railroad routes to the interior are possible and have been considered by those interested in building a road. Preliminary surveys, furthermore, have been made over each. Each route overlaps some one of the others in part of its course and all have difficulties to surmount. Two of the four routes originate from Valdez and two from points adjacent to the mouth of Copper River. The first one from Valdez is practically that of the government trail. It follows Lowe River to Thomson Pass, over which it proceeds to the head of Tsina River, or South Fork of Tiekel River, as it is more generally called, and then continues northward to Tonsina. The sec-

ond ascends Lowe River to its head, crosses Marshall Pass to Tasnuna River, and after descending that stream follows the west bank of Copper River northward. Of the two strictly Copper River routes one starts from Cordova Bay in Prince William Sound, 24 miles west of the river's nearest point; the other from Katalla, nearly 17 miles southeast of Cottonwood Point, the southern extremity of Copper River's east bank.

There are not sufficient data at hand for a thorough discussion of these routes, but some of their advantages and difficulties may be pointed out. It will be seen that there are some discrepancies between distances given here and elsewhere, arising from the use of railroad surveys in connection with small-scale maps. The given elevations,

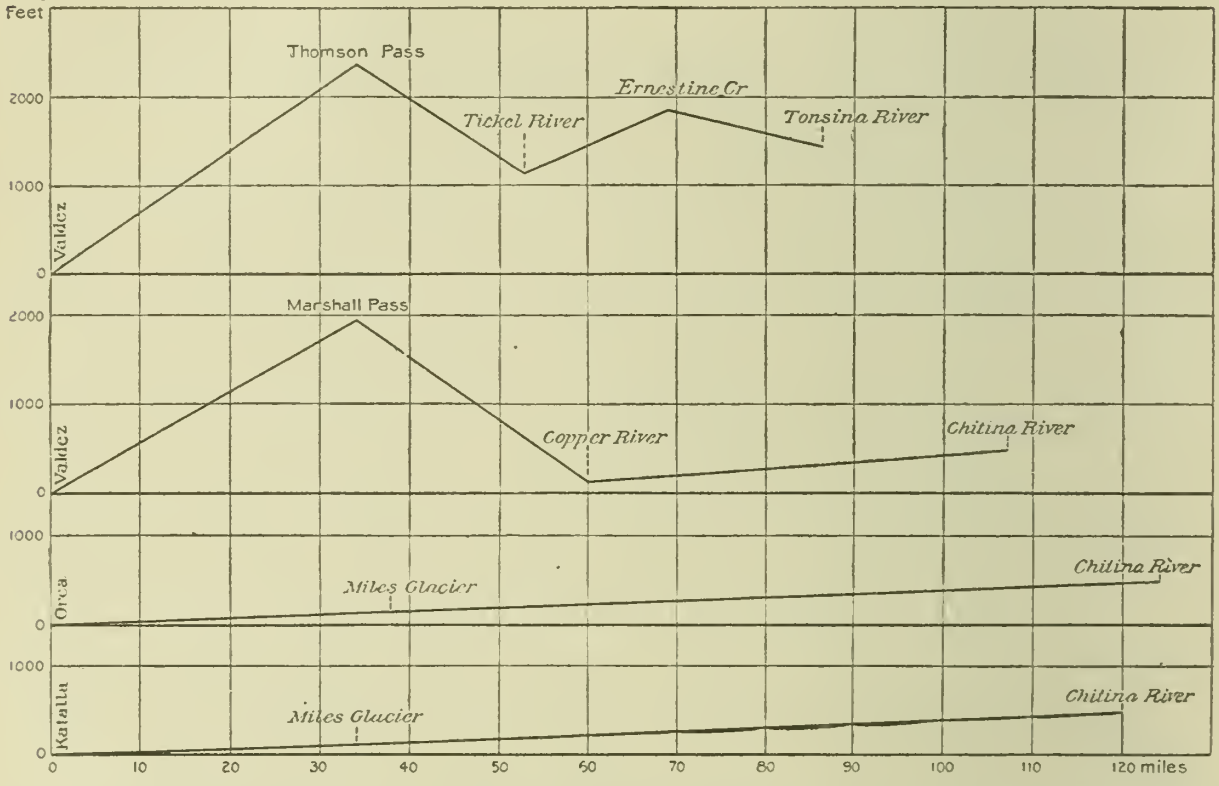


FIG. 1.—Comparative grades of the four proposed railroad routes from the coast to the interior Copper River basin.

too, take no account of minor grades and are therefore minimum quantities—less than the total number of feet a locomotive must rise in going from tide water to the interior points indicated.

The Tonsina route has the most difficult grades. (See fig. 1.) From Valdez to Thomson Pass, 34 miles distant by the railroad surveys, there is a climb of 2,370 feet. Then comes a descent of 1,250 feet in 19 miles to Tiekel River, followed by an ascent of 710 feet in 16 miles to the Ernestine divide. From Ernestine to Tonsina, 16 miles, there is a descent of about 400 feet. It will be seen that the total of the distances here given is 86 miles, or 6 miles greater than the distance from Valdez to Tonsina given by the road commission.

The greatest obstacles encountered on this route are the Keystone Canyon of Lowe River and Thomson Pass, by which the coast range is crossed. These involve a great deal of rockwork and are subject to deep snows and snowslides in winter. The latter difficulty, however, will be met on any route.

Less difficult grades are presented by the Tasnuna route. From Valdez to Marshall Pass, 34 miles, there is a rise of 1,860 feet. Then comes a fall of 1,740 feet in 26 miles to Copper River. From Tasnuna River mouth to Chitina River, 47 miles, is an ascent of 370 feet. The difficulties of Keystone Canyon are encountered on this route also, but Marshall Pass is 500 feet lower than Thomson Pass, and the heavy grade from Tiekel to Ernestine is avoided.

The two Copper River routes have practically the same grades (see fig. 1), a rise of 480 feet between the coast and Chitina River. The distance from Katalla to Chitina River is 120 miles, and from Eyak or Cordova Bay slightly farther, about 124 miles.

A railroad from Katalla involves the construction of a harbor available at all seasons where ships can discharge their cargoes in safety. A bridge over Copper River is required immediately above Childs Glacier, but there is no rockwork, except a mile or two at Katalla, till Abercrombie Rapids have been reached. Two railways are located and under construction at Katalla. One runs west from the town and then northwest to Copper River, but has a spur up Katalla River to Bering Lake and the coal fields; the other ascends Katalla River and reaches Martin River, which it descends to the Copper by the Lake Charlotte divide. The Lake Charlotte route thus passes through the coal field. Each of these Katalla roads has its own plans for a separate breakwater and terminal facilities.

Cordova Bay, in contrast with the open roadstead of Katalla, is a protected body of water that can be entered at any time, but a road from this place involves rockwork below Abercrombie Rapids and two bridges over Copper River in order to avoid Childs Glacier. Furthermore, it will be necessary to build a branch line to the coal fields. The upper bridge, between Childs Glacier and the little lake fronting Miles Glacier, can probably be built without unusual trouble, since it is not long and the foundations are believed to be good, but as to the bridge below Childs Glacier there is uncertainty that will not be removed till the nature of the river's bottom has been more fully examined.

Northward from Abercrombie Rapids the Katalla and Cordova Bay routes are the same, and above Tasnuna River they also coincide with the Valdez-Tasnuna route, following the river's steep west bank. Immediately above the rapids is the moraine or stationary débris-covered lower end of Baird Glacier. This is overgrown with a thick

growth of alders and extends down to the river's edge, where the underlying ice has been exposed occasionally in test pits. It is known as "dead glacier" and must be traversed for several miles by any road following the west side of Copper River. The surface is sometimes disturbed by melting of the ice beneath, but whether this will cause serious difficulty in maintaining the track is perhaps doubtful. Between Baird Glacier and Chitina River much of the roadbed must be cut from the solid rock, but it is not believed that any unusual engineering difficulties will be met.

A great advantage of the two Copper River routes, in addition to their lower grades, is their nearness to the Controller Bay coal fields. This is doubtless one reason why they are regarded with greater favor than the shorter routes from Valdez.

VEGETATION AND CLIMATIC CONDITIONS.

Chitina Valley is a timbered region and furnishes a supply of wood suitable for most of the miner's requirements. The greater part of the timber is spruce, but cottonwood is abundant on many river banks and deltas; and though it is of little value for lumber, it is nevertheless useful for some purposes. The broad, marshy, valley lowland supports a scanty growth of very inferior spruce and of aspen. Better timber grows along the borders of the lowland and on the lower mountain slopes. It covers the slopes to an elevation varying from 2,000 to 3,000 feet above sea level, but trees growing near timber line are of course dwarfed and of little use except for firewood. Near glaciers or in the narrow valleys leading to them the timber line does not reach as great an elevation as on the interstream slopes. Some of the best timber in the valley grows in the vicinity of Chititu and Young creeks. Trees 18 inches in diameter at the butt and tall enough to give two 16-foot cuts are not unusual, but the large majority of them are smaller than this.

South of Chitina River between Nizina River and the Copper there is a heavy growth of spruce on the north slopes of the mountains. It is of much poorer quality, however, than that on the Wrangell Mountains. The wood is brittle and has little strength. Most of the trees, too, are of small diameter and will probably be of more value as fuel for the steamboat *Chitina* than for any other purpose.

Inadequate and expensive means of transportation have been the chief obstacle in developing the copper resources of Chitina Valley, but another adverse condition, which, however, affects prospecting more than mining, is the short summer season. Up to the present practically all supplies have been carried during the winter with sleds drawn by horses. In the earlier days dogs, or even man power,

were sometimes used, but in later years horses have been employed almost entirely. Sufficient feed to last till grass starts in the spring is carried in from the coast, but after spring most horses "live on the country." Early snows come about the end of August, so that between a late spring and an early winter horses can not be expected to find their own feed longer than from approximately the first of June till the first of September. Grass is always abundant near timber line in June, July, and August, and good pasture is usually found at lower elevations after the timber has been burned off for a number of years. Some of the prospectors have provided their stock with fine feed by following this practice of burning off the timber. Horses frequently have difficulty in finding feed in the timbered valley bottoms, even in midsummer, but in the fall, after frost has killed the grass on the mountains, the river bars afford a plant known locally as "pea vine," of which horses are very fond and which is excellent forage. Since most prospectors use at least one or two horses for packing in summer and for hauling supplies in winter, it is readily seen that the matter of horse feed has a great influence in determining the number of available working days in a summer. The prospecting season is still further shortened by the fact that in the high mountains, where most of the copper ores have been found, much snow often remains till the first or even the middle of July.

Figures for the yearly precipitation and temperature are not available, but it may be said that the extremes of temperature in summer and winter are much greater than on the coast and that the rainfall is very much less.

HISTORY.

Native copper from the Chitina (*chiti*=copper and *na*=river) Valley was used by the Copper River Indians before white men entered the country. Spear and arrow heads of copper were made by them and have been found in the sluice boxes by miners on Chititu and Dan creeks. Ceremonial knives of copper are even now employed by the natives for cutting the first salmon caught in the beginning of the season's run. Lieutenant Allen relates that Nikolai showed him specimens of bornite and told him of native copper on Chititu Creek. He also showed him bullets of native copper obtained from natives "over the mountains," probably at the head of White River. A much-worn wooden shovel and birch bucket, found in the loose waste below an outcrop of native copper in amygdaloidal greenstone on Glacier Creek, a tributary of Chitistone River, indicates that the Indians also knew of native copper in place at that point. Whether they had any knowledge of the presence of gold on Chititu and Dan creeks is not known to the writers.

White prospectors first appeared in the Chitina Valley in 1898, their presence resulting from the general interest aroused in Alaska by the discoveries at Dawson two years before. Spencer,[a] after visiting the region in 1900, says:

> The occurrence of rich copper deposits within the basins of Copper and Chitina rivers has been commonly reported for many years, but it was not until the summer of 1898 that efforts to locate ores proved successful. In this year several prospectors reached the interior and made some locations, while in 1899 a number of men penetrated the Wrangell Mountains by way of Kotsina River and discovered good indications at many places; others, exploring toward the east, proved the continuance of the copper-bearing belt in the direction of White River, where copper occurs in important quantities. In this region the Nikolai mine was discovered in July, 1899, under the guidance of a native sent by Chief Nikolai. During the summer of 1900 several prospecting parties were operating in the Kotsina and Chitina regions, and many additional locations were made, and upon the most promising properties considerable development work was done.

The Bonanza was discovered about the end of July or the first of August, 1900, by two prospectors, Clarence Warner and Jack Smith, who staked the property. It was discovered independently two or three weeks later by A. C. Spencer, of the Geological Survey party, who found it while tracing the limestone-greenstone contact eastward from Kennicott Glacier. Warner and Smith were members of a party acting under an agreement to share whatever minerals might be discovered. Some of the men were also bound to divide their interest with others, not members of the party, who had furnished them with supplies—"grubstaked" them. In consequence of this complication of ownership the property became involved in litigation that was not settled for several years.

The Nizina gold placers were discovered in 1901, but the rush of prospectors to the region did not begin till the following year. A large number of men left Valdez for the upper Chitina in June and July, 1902, and Dan, Chititu, and Young creeks, besides others, were prospected and staked. After the richest and more easily handled gravels were worked over the claims were sold or abandoned and gradually came into the hands of fewer individuals, so that now most of the claims on Dan and Chititu creeks are included in three separate ownerships. There has been little mining on Young Creek.

GENERAL GEOLOGY.

INTRODUCTION.

In the following account of the geology of the Kotsina-Chitina region the descriptions are confined to the area between Chitina River and the summits of the Wrangell and Skolai mountains rep-

[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska; a special publication of the U. S. Geol. Survey, 1901, p. 82.

resented on the geologic map (Pl. II). This map is reproduced from the report of Schrader and Spencer (1901), but has received such corrections in some of its lesser details as were indicated to be necessary by the later work of Mendenhall (1902) and by the more recent work of the Survey party in 1907. The formation names used by Schrader and Spencer on the map and in the description are here retained.

In outline the important facts concerning the geology are as follows: Both sedimentary and igneous rocks are encountered. Four principal formations, including the unnamed Triassic shales and limestones, occupy most of the area and appear throughout its length from east to west. These formations, in order from oldest to youngest, are the Nikolai greenstone, the Chitistone limestone, the Triassic limestones and shales, and the Kennicott formation. These rocks have been folded and faulted, but the metamorphism is not great. It is most noticeable in the greenstone but has hardly affected the Kennicott formation.

The Nikolai greenstone consists of a succession of basaltic lava flows and is overlain conformably by the massive Chitistone limestone. This limestone is of Triassic age and is succeeded without any known interruption in deposition by other Triassic rocks—limestones and shales—consisting of a lower member made up of interbedded thin limestones and black or gray shales and an upper member formed almost entirely of shale. The Kennicott formation is in large part a conglomerate, but includes limestone, sandstone, and shale beds. Its age is Upper Jurassic or Lower Cretaceous and its deposition was separated from that of the Triassic shales by a long erosion interval, so that in some places it is found to lie unconformably on the greenstone, in other places on the limestone or on the limestone and shales. In addition to the sedimentary rocks that have been mentioned, there is in the western part of the district an area of limestones, shales, and conglomerates with associated sills or flows of basalt of unknown age that has not been correlated with any of the four first-named formations, and there are also in the eastern part of the district at least two areas of coal-bearing rocks that are perhaps younger than any of the four major formations.

The igneous rocks, in part extrusive and in part intrusive, are represented by both basic and acidic types. A list of these includes gabbro, diabase, diorite, andesite, granite, and rhyolite. Surface flows, mostly andesite, and fragmental volcanic deposits, chiefly rhyolite, cover relatively large areas in the western part of the district and higher parts of the Wrangell and Skolai mountains. Surface flows of diabasic character that have been covered by younger sedimentary deposits have their most important representative in the Nikolai greenstone previously mentioned. Intruded porphyritic dikes related

to the diorites are very abundant in places, particularly in the Triassic limestones and shales. Only one considerable mass of the lighter-colored granitic intrusives, however, is represented on the map, and gabbro, so far as is now known, is restricted to 3 localities.

The principal unconsolidated deposits of the region comprise sands and gravels deposited in water and the more poorly sorted or unsorted fragmental material resulting from glacial activity. They are most extensive in the broad lowland bordering Chitina and Nizina rivers, but are well developed in most of the tributary valleys.

The geologic map (Pl. II) shows the general distribution and areal relations of the rocks that have been briefly described. It is given in practically the same form as when first published in 1901, but a few changes have been made, particularly in the vicinity of Elliott Creek. Furthermore, the representation of the Chitistone limestone in the southeastern part of the area has been omitted. This region was not visited in 1907 and was seen only from a distance by geologists of the Survey party in 1900. Prospectors report that limestones outcropping near the Chitina on its north side above Tana River are not part of the Chitistone limestone. That the identification of this limestone was doubtful was also suggested in the original report, and it has therefore seemed best to omit it on the accompanying geologic map. One other change of less importance has been made in mapping the vicinity of Hidden Creek west of Kennicott Glacier.

The detailed geologic descriptions which follow are quoted almost entirely from the published report of Schrader and Spencer.[a] Such portions of that paper as deal with areas outside the limits of the area here under discussion are omitted. A few explanatory words are inserted in brackets. Some new material is introduced, and a few changes are made where later work has shown the earlier conclusions to be inaccurate. The most important change appears in the substitution of Chitistone for Carboniferous in those places where Carboniferous was used to indicate the massive Triassic limestone. The error arose from a lack of fossil evidence with which to determine the age of the Chitistone limestone and from an attempt to correlate it on stratigraphic and lithologic grounds with the massive "Upper Carboniferous" limestone at the head of White River. It has been necessary on account of the substitution to change the original wording slightly in one or two places, in order that there may be no mistake concerning the age of the limestone and that the close relation between the Chitistone limestone and Triassic limestones and shales may appear.

[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska, a special publication of the United States Geological Survey, 1901, pp. 40–62.

The account of the unconsolidated Pleistocene and Recent deposits is entirely rewritten in such a way that the general discussion of these deposits as occurring in the Copper River Valley is not taken up.

UNDETERMINED ROCKS ON KOTSINA RIVER.[a]

On either side of Kotsina River and extending from the edge of the andesite west of Long Glacier and the region about Clear Creek southward to Elliott Creek there is a series of rocks whose relations and age have not been determined. They are made up of sediments, including limestones, shales, and coarse conglomerates, with intercalated sheets or flows of basalt like the Nikolai greenstone. The pebbles of the conglomerate are composed of greenstone material.

The series shows a general dip toward the southwest, and in this regard it follows the structure of the Nikolai greenstone and the Chitistone limestone which occur farther up the river. The age of the series is unknown, but from the structure it would seem that it must be younger than the Chitistone, which appears to dip beneath it. Owing to its make-up, however, and the fact that it has been affected to a certain extent by metamorphism, it seems impossible to correlate it with the adjacent Triassic strata. If, however, it is older than the limestone, it may be representative of a series equivalent to the Orca rocks occurring in Prince William Sound. This suggestion is made in the most tentative way, since there is no evidence at hand for the determination of the stratigraphic position of the series. For this reason it has been represented on the map as unknown sediments.

In cross section C–D [Pl. II] a fault is suggested to explain the relation of the rocks shown on the map in the region of Copper and Pass creeks. The existence of such a fault would also explain the occurrence of the unknown series in its observed relations, on the supposition that it belongs beneath the mass of the Nikolai greenstone.

NIKOLAI GREENSTONE.[b]

Description.—The term "Nikolai greenstone" is employed to designate a series of volcanic flows forming an important mass in the Wrangell district. The rock shows considerable variation from place to place, both laterally and vertically, in the separate flows. In color it is generally green, though in some places it is of a reddish hue. In texture it varies from fine-grained, very densely crystalline, to rather coarse-grained porphyritic, and in many places it shows amygdaloidal characters. Under the microscope the rock is found to consist of feldspar and augite, with considerable quantities of two green minerals, which are found to be chlorite and serpentine. In rare instances grains of olivine are noted under such conditions that it seems certain that the serpentine had its origin in the alteration of the olivine. The structure is always that which is characteristic of diabase, where the laths of feldspar form a feltlike mesh with augite lying in the interstices. At times the rock is so fine grained that it becomes almost aphanitic, while at other times the crystals of feldspar have dimensions reaching several millimeters. When amygdaloidal, as it frequently

[a] Schrader and Spencer, op. cit.

[b] Greenstone is a word sometimes used in an indefinite noncommittal way to designate altered igneous rocks that may differ much in other ways but possess the common characteristic of green color. The term "greenstone" is perhaps most frequently applied to certain metamorphosed diabases or diabase tuffs, but is also used in connection with altered diorites and gabbros.

is, the cavities are filled by chlorite or serpentine, either with or without chalcedonic quartz. Accessory magnetite is always present and frequently in considerable amounts; also in many cases metallic sulphides are present, though these are probably of secondary origin. Locally metallic copper occurs in grains or stringers, but always under such circumstances that it may be considered of secondary rather than primary origin. The composition and structure of the Nikolai greenstones show them to have been originally typical basalts. * * *

Occurrence and distribution.—The Nikolai greenstone occurs in many places in the Wrangell and Skolai mountains and wherever seen is found to show the same relations to the sedimentary series of the region. The massive Chitistone limestone, which is the lowest unmetamorphosed sedimentary formation of the district, lies directly upon the greenstone in such a way that it would seem as if it had been originally laid down upon the surface of the earlier volcanic flows. In this relation it is observed in the upper part of Kotsina River, where the greenstone passes beneath the Chitistone limestone, dipping toward the southwest, and forms a large part of the mountain masses that are drained by the southern glaciers of the Kotsina basin. From this region it connects directly with the occurrence in the mountains in the vicinity of Kuskulana Glacier, and, reappearing in the valley of the Lakina, is again found in the upper part of the Kennicott drainage, whence it may be traced (always bearing the same relation to the massive limestone) across McCarthy Creek and thence to the Nizina and the mountains to the east. [See Pl. III, *A*.]

The thickness of the greenstone flows is not known, for while the top is easily determined the bottom has not been recognized with certainty. In the upper Kotsina basin the Nikolai greenstone as represented on the map includes some tuffaceous beds, hard, gray, siliceous or silicified beds (perhaps tuffaceous also), cherty beds which are possibly a variation of the siliceous beds last mentioned, and even some dark-gray or black slates. It is probable that on closer study the Nikolai greenstone may be divided and the word greenstone applied to only a part of the succession in such a way as to more nearly conform with the stricter use of the term.[a] The Nikolai greenstone as it is mapped probably has its greatest thickness in the upper Kotsina country, where it was estimated by Schrader and Spencer as roughly 4,000 feet thick.

Structure of the greenstone.[b]—From the origin of the greenstone series, through the successive outflow of innumerable sheets of basalt, it is natural that the complex should show a bedded character comparable to stratification in sedimentary rocks, and in many places this structure is very well exhibited. The bedding in the volcanic series is always found to be in accord with the structure of the overlying water-laid formations.

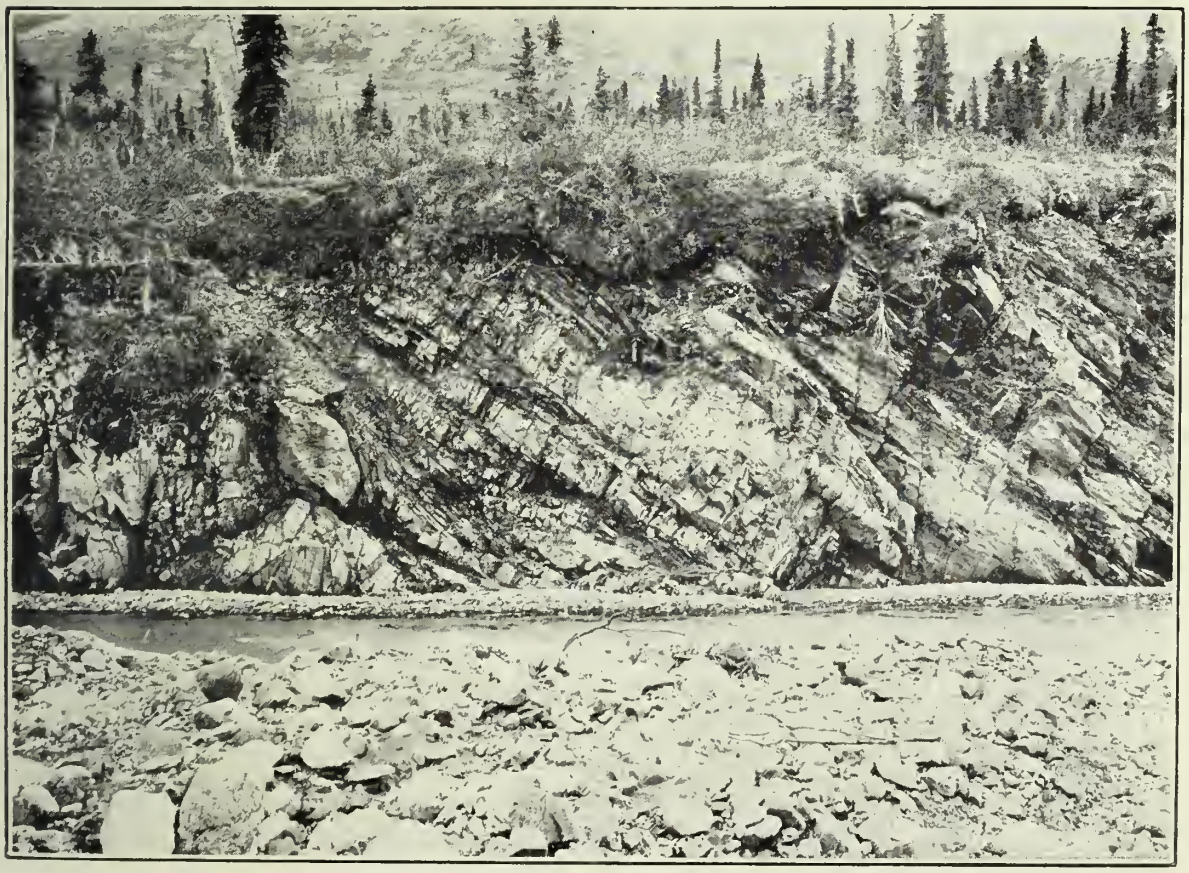
Locally the greenstone shows a secondary structure due to shearing [as illustrated in Pl. III, *B*], which is reproduced from a photograph taken below Surprise Creek on Kotsina River. * * *

Age of the greenstone.—Concerning the actual age of the Nikolai series little can be said. They are older than the Chitistone limestones which rest upon

[a] The possibility of correlating part of the Nikolai greenstone succession with some of the interbedded Carboniferous shales, tuffs, and lava flows examined in 1908 in the region about Skolai Pass and the head of White River is suggested.

[b] Schrader and Spencer, op cit.

A. CONTACT OF NIKOLAI GREENSTONE AND CHITISTONE LIMESTONE, WEST OF NIZINA RIVER, NEAR NIKOLAI MINE.



B. SHEARED GREENSTONE ON SOUTH SIDE OF KOTSINA RIVER, BELOW SURPRISE CREEK.

them, though probably not very much older, since there seems to be no folding in the interval between the close of the volcanic outflows and the beginning of marine sedimentation. * * *

The evidence that the greenstone was formed previous to the Chitistone limestone is as follows: Wherever the two are in contact the limestone shows no metamorphism, such as usually results from the intrusion of a calcareous rock by an igneous mass; the pseudostratification in the greenstone is parallel with the bedding of the overlying limestone wherever observed, and the layers in the former are different in structure and general appearance. These facts, and the frequent occurrence of amygdaloidal phases in the greenstone and extremely marked variations in the coarseness of crystallization within short distances, are distinctly in favor of the origin of the greenstone by successive flows of basalt at a date preceding the deposition of the limestone. Furthermore, there are no dikes or irregular intrusions of the basalt which can be definitely shown to cut across the Triassic strata, a condition which could hardly exist if the greenstone had been forced into the sedimentary rocks in the form of a long laccolith at a constant horizon. * * *

CHITISTONE LIMESTONE [TRIASSIC].

Description.—The Chitistone formation is composed of very massive limestones, without any important intercalations of shale. When weathered, it has a white or gray color, which makes it prominent in contrast with the greenstone upon which it lies, but when broken it is found to have a blue color, which is indicative of considerable carbonaceous material in its composition. In texture it is fine-grained throughout.

Occurrence and distribution.—The massive Chitistone limestone is one of the most prominent formations of the Wrangell region. It is found lying above the greenstone in the upper part of the Kotsina basin, where it crosses the river at the mouth of Kluvesna Creek. Northwest of this place it has been traced as far as Long Glacier, which comes down from the slopes of Mount Wrangell, but beyond this glacier it is hidden by recent flows of andesite. Southeast of the Kotsina the limestone is found at various localities, which can not be connected upon the surface, since there are overlying unconformable deposits on the higher mountains, but the main outcrop may be traced toward the southeast to the divide between Rock Creek and the Kuskulana, and thence in the mountains which lie between Strelna Creek and Kuskulana River the formation is prominent. It is thought that the limestone may also occur on the southwestern slopes of the mountains beyond where the Kuskulana comes out into the open basin of the Chitina Valley, but no observations have been made on this vicinity. At a point a mile or so above Trail Gulch, on the east side of Kuskulana River, the limestone appears, and, rising rapidly above the massive Nikolai greenstone, soon reaches the tops of the mountains lying south of Kuskulana Glacier. East of the first prominent creek on the south side of the eastern fork of Kuskulana Glacier observations have not been made, but from the distant view obtained of the upper part of the drainage it seems that the massive limestone is not present. Its absence must be explained through folding or faulting, the nature of which could not be ascertained. The limestone appears again on the east side of Lakina River above the lower end of the glacier, where it rises rapidly toward the northeast, and while probably it connects directly with the exposure on the west side of the Kennicott drainage it has not been so represented on the map because of the lack of sufficient observations. On the east side of the mountains between Lakina and Kenni-

cott glaciers the limestone is very well exposed, and dipping slightly toward the north appears in the mountain between the first forks of the glacier, and again across the eastern fork about 7 miles above the foot of the glacier. From this place the massive stratum can be traced across McCarthy Creek to the head of Nikolai Creek and to Nizina River. In the region between Kotsina River and the Lakina the general dip of the formation is southward, but from the Kennicott to the Nizina the structure is in the opposite direction, the dips varying from 20° to 60°. This structure is indicative of an anticlinal axis having a general northwest-southeast direction.

East of Nizina River the structure is more complex, and while the dips are not so steep the simple anticlinal structure gives place to a series of broad folds at times showing quaquaversal dips, so that erosion has revealed the underlying greenstone at various places both along the Nizina and on the tributaries which join it from the east. A view of the drainage basin of Skolai Creek shows the limestone rising gradually toward the White River divide, with greenstone lying in the valleys. At the mouth of Chitistone River the limestone comes to the valley bottom on the north side, while on the south it is from 1,000 to 1,500 feet higher, and between the forks the greenstone reaches to the top of the mountain. From the lower side of the Chitistone the formation may be traced along the side of the mountain until the upper part of the creek [Dan Creek] which joins the Nizina at Nikolai House is reached, where the rocks are seen to be descending. [The character of the contact between the limestone and the underlying volcanic series is illustrated in Pl. III, A, which also exhibits some of the structural features that have been mentioned.]

Southward from the stream [Dan Creek] which joins the Nizina at Nikolai House the limestone is not found, and it seems necessary to suppose that its absence is due to a fault which follows the general course of this tributary. The mountains to the south are composed of black shales intruded by igneous dikes, and are supposed to belong to the Triassic series lying west of the Nizina. The same series is found south of the belt of greenstone without the occurrence of the limestone between, so that it seems probable that the supposed fault extends toward the west at least as far as Lakina River. The general line of the displacement has been represented on the geological map. * * *

Thickness of Chitistone limestone.—Studies of the [Chitistone limestone] and [the other] Triassic strata of the Wrangell district have not been sufficiently detailed to afford evidence as to where the line between these two formations should be drawn. Above the massive basal series of limestones there is a series of thin-bedded limestones with shaly partings which is apparently in perfect conformity with the underlying beds and which passes by gradation into the black shales above. These black shales contain the fossils by means of which the Triassic age of the formation has been determined. The provisional and arbitrary line between the two formations has been placed at the top of the massive limestone series. The thickness of the Chitistone formation, as thus defined, is somewhat variable. Its maximum development is probably in the region of Nizina River, where it reaches a thickness of approximately 2,000 feet. In the Kotsina and Strelna region its thickness is somewhat less, but it can not be made out that there is any progressive thinning toward the west.

Age of the limestone.—There has been doubt concerning the age of the Chitistone limestone, owing to the fact that no determinable fossils were collected from it until the summer of 1907. Schrader

and Spencer correlated the Chitistone with the massive limestone near the head of White River on Kletsan Creek, described by Brooks.[a]

Schuchert, who determined the fossils collected by Brooks, states: "These two localities are of one general horizon in the Upper Carboniferous. * * * I have made no specific determinations, since the fauna is not to be correlated with that of the Upper Carboniferous of the Mississippi Valley, but with the *Fusulina* zone of China, India, and the eastern slopes of the Urals." At a later date, however, Schuchert assigned the White River rocks to the Permian.[b]

Mendenhall, on the assumption that the Chitistone had been correctly correlated with the limestone at the head of White River, accepts provisionally the Permian age of the Chitistone. He evidently felt that the correlation was a doubtful one, however, and sums up the evidence for and against the Permian age of the Chitistone limestone as follows:[c]

For Permian age:

1. The Chitistone is geographically very near and lithologically very similar to the Permian north of Skolai Pass.
2. It lies beneath known Triassic.
3. There is no similar heavy limestone in the known Triassic.

Against Permian age:

1. The Chitistone heavy limestone and the thinner beds above it are nonfossiliferous, while the Permian in other localities is very fossiliferous.
2. The Chitistone seems to lie conformably below known Triassic, while the known Permian lies unconformably below Triassic when the relations are shown.
3. The Chitistone is free or nearly free from basic intrusives and overlies basic effusives, while the known Permian near by is extensively intruded by basic masses.

In 1907 fossils were collected from the Chitistone limestone at a number of localities between Kotsina River and Chitistone River, and they definitely determine its age as Triassic. Part of these fossils were found in place, but a majority were collected from the talus débris below cliffs of the limestone, yet there was no place where it seemed possible that the limestone fragments containing the fossils could have come from any other source than the cliffs above them, and no hesitation is felt in accepting their evidence for the age of the Chitistone. The fossils were determined by T. W. Stanton, who describes them as follows:

Several different localities are represented in the collections, but the fossils, with one exception, are all said to be from the Chitistone limestone and closely associated formations. The collection is small and somewhat fragmentary, but

[a] Brooks, Alfred H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 359.

[b] Mendenhall, W. C., Geology of the central Copper River region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1905, p. 43. On the other hand George H. Girty believes that all the sedimentary beds of Alaska that have been described as Permian are "Upper Carboniferous."

[c] Op. cit., p. 51.

it has proved sufficient to show quite conclusively that the beds in question are of Triassic age. The ammonites, especially, are all characteristic Triassic types, and the few brachiopods obtained are also Mesozoic. There is no indication of Paleozoic fossils in any part of the section represented.

The single ammonite from Chititu Creek is of more modern types and most probably comes from the Jurassic.

The following lists give the forms recognized from each locality. In most cases specific identifications have not been possible, but this does not lessen the accuracy of the age determination.

4804. No. 1. Elliott Creek, from beds above Chitistone limestone. *Pseudomonotis subcircularis* (Gabb). A single imperfect specimen of this Triassic species.

4805. Nos. 2 and 23. Hoodoo or Mullen claim on Copper Creek, Kotsina River. Chitistone limestone. *Hinnites?* sp. Undeterminable cross section of ammonites.

4805. Nos. 3 to 6. Chitistone limestone. Talus on Copper Creek. *Terebratula* sp., *Spiriferina* sp., *Hinnites?* sp., *Pleuromya?* sp.

4806. No. 7. Crawford's Skyscraper claim on Roaring Creek, Kotsina River, Chitistone limestone. *Natica?* sp. Undetermined bivalve fragments.

4808. Nos 9, 14 to 19, 21, 22. Bonanza mine and Bonanza Creek. Undetermined corals. *Terebratula* sp., *Spiriferina* sp., *Hinnites?* sp., *Pseudomonotis subcircularis* (Gabb)?

4809. Nos. 10 to 13, 20. Jumbo Creek near the Bonanza mine. *Pentacrinus* sp., *Terebratula* sp., *Avicula?* sp., *Arcestes?* sp. (cross section), *Juvavites?* sp. The last two named are certainly Triassic types of ammonites and probably belong to the genera to which they are provisionally assigned.

4810. Nos. 24, 25. South side of Chitistone River at Houghton-Alaska Company's prospect. *Spiriferina?* sp., *Halobia* sp., *Arcestes?* sp., *Tropites?* sp. The last two are Triassic ammonites provisionally identified from imperfect specimens.

4811. No. 26. Chititu Creek. *Perisphinectes?* sp. This ammonite is not a typical *Perisphinectes*, but it is probably of Jurassic age—certainly not older than Jurassic.

TRIASSIC LIMESTONES AND SHALES.

Description.[a]—The rocks which have been included in the Triassic [limestones and shales] series comprise all the strata that lie above the Chitistone limestone and below the unconformable Kennicott formation of Jura-Cretaceous age. In the lower part, and resting conformably upon the Chitistone limestone, is a series of thin-bedded limestones, in strata from a few inches to a foot or more in thickness, supported by thin partings of black shale (Pl. IV, A). The thickness of this member is approximately 1,000 feet, and the limestone, so far as observed, did not contain fossil remains. Above the thin-bedded limestones, and sharply defined from them, are black shales containing occasional bands of impure limestone, locally affording fossils, from which the age of the formation has been determined. The thickness of the upper member of the Triassic is very great, possibly more than 3,000 feet, but no opportunity was offered for its direct measurement, since its occurrence beneath strata lying unconformably upon it, together with the attitude which it has assumed as the result of folding and faulting, renders its relations complicated and obscure. A few thin flows of greenstone, similar to that of the Nikolai series, were observed here and there interbedded with the black shales of the Triassic. The

[a] Schrader and Spencer, op. cit.

A. THIN-BEDDED TRIASSIC LIMESTONE AND SHALE ON WEST BRANCH OF ROCK CREEK.

B. CRUMPLING IN THIN-BEDDED TRIASSIC LIMESTONE ON RIDGE EAST OF GILAHINA CREEK.

Triassic [limestones and shales] series may be easily recognized from its general homogeneous nature and the fine-grained character of its black carbonaceous shales.

Locally the thin-bedded limestones are very intricately folded and contorted, a feature which is well shown in the ridge formed of Triassic rocks at the head of Gilahina Creek [and is illustrated in Pl. IV, *B*].

Occurrence and distribution.—The Triassic rocks [limestones and shales] are found dipping toward the southwest in the Kotsina region, and may be traced in a continuous band southwestward [southeastward] to Kuskulana River and from the east side of that stream to Lakina River and thence to the Kennicott and Nizina. East of the Nizina they occur principally in the region south of the great fault which limits the Chitistone limestone, and in the region south of the Nizina the black shales reach across Chitina and Tana rivers and come in contact with rocks of the Valdez[a] "series." Their occurrence in the vicinity of Skolai Pass is reported by Hayes. * * *

In the region south of the fault and east of Lakina River and again east of this region as far as the mountains beyond the Nizina the Triassic shales are very intricately intruded by dikes and sheets of porphyry.

Fossils of Triassic beds.—Only two recognizable fossil forms have been determined in the material which was collected from the Triassic beds, but these are considered sufficient to fix definitely the age of the series. T. W. Stanton, of the Geological Survey, reports the following forms of Upper Triassic age: *Monotis subcircularis* Gabb and *Daonella* like *D. lommeli* Wissmann.

DISTURBANCES FOLLOWING DEPOSITION OF TRIASSIC.

The formations next younger than the Triassic shales in the Copper River region were deposited at the close of the Jurassic or the beginning of the Cretaceous—that is, at a time corresponding to the deposition of the Knoxville beds of the northwestern United States. These latter rocks are unconformable upon the Triassic and older formations and previous to their formation the older rocks had been folded and raised above the sea and their upturned edges reduced by the process of erosion. The close of Triassic deposition in the western and southwestern portions of the continent has been very generally recognized as a period of mountain building and of geological revolution. It is supposed by Dawson that at this period the Vancouver and coast ranges of British Columbia were outlined, and that there was probably at the same time some corrugation along the line of the Rocky Mountains.[b] The result of this disturbance in the Wrangell district was the production of the broad folds which have been recognized from the attitude of the Nikolai greenstone and the overlying sediments. The period of erosion which followed the uplift and

[a] The term Valdez "series" was first used by Schrader in a report entitled "A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska, in 1898" (Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 408) to describe the rocks typically developed in the vicinty of Valdez. The Valdez "series" includes a succession of highly metamorphosed sedimentary beds and consists of "bluish-gray and dark quartzites, arkoses, and quartz schists, interbedded with generally thin beds of dark blue or black slate, shale, mica schist (in some places highly graphitic), nodular mica schist, and occasionally some stretched conglomerate." So far as is now known the Valdez "series" makes up the greater part of the Chugach Mountains. Its rocks are exposed along Copper River from the vicinity of Wood Canyon at least as far south as Baird Glacier. It is not known how far eastward they extend.

[b] Dawson, George M., On the late physiographic geology of the Rocky Mountain region in Canada, with special reference to changes in elevation and to the history of the glacial period: Trans. Roy. Soc. Canada, vol. 8, 1890, sec. 4, p. 6.

folding was a very long one, since the amount of rock removed must necessarily have been measured by several thousand feet.

The general trend of the folds in the Triassic rocks is parallel with the structure of the adjacent Valdez "series." This older structure is very uniform throughout the whole region from the coast to Copper River, and it is only natural that the recurrence of dynamic action in the region should have produced structures in accord with the lines of weakness that were developed at a very early date.

The Nikolai greenstone and the sedimentary formation which lie conformably above it are at present found to be considerably jointed and cut by fissures. It is probable that this fracturing of the rocks was produced during the post-Triassic disturbance, though it is reasonable to suppose that subsequent movements, which must have accompanied the volcanic phenomena of the region, may have caused additional fracturing and folding of the rocks.

It is believed that the eruptive phenomena of the Wrangell region may have begun during this period of disturbance, but there is no evidence to show that the intrusion of the Triassic shales occurred at this period rather than at a much later date, when, as is known, volcanic forces were very active.

KENNICOTT FORMATION.

Description.—The strata which, on the evidence of fossils, have been assigned to the Upper Jurassic or Lower Cretaceous consist of a variable series of conglomerates, sandstones, limestones, and shales. The formation lies unconformably upon the upturned edges of the older rocks, resting in different places upon the Nikolai greenstone, the Chitistone limestone, and the shales of the Triassic. In places it appears that these older formations were completely leveled by erosion previous to the deposition of the Kennicott formation, but elsewhere the relations, though obscure, are indicative of the probability that deposition took place in narrow, deep lagoons.

At the base of the formation there is usually a conglomerate or coarse sandstone composed of materials derived from the greenstone and from the limestones and shales, with an admixture of quartz sand. Above this there are alternations of green sandstone with black shales, and occasionally bands of limestone, in places containing considerable sand.

Occurrence and distribution.—The northernmost known occurrence of the Kennicott formation is at the head of Limestone Creek between Clear and Kluvesna creeks. Here the formation is in contact with the Chitistone limestone and with the Triassic shales. South of this there is an outlier resting upon the shales, forming the top of a high peak between Clear Creek and Kluvesna Creek north of Kotsina River. South of the Kotsina the formation is found usually capping the highest ridges, where it rests upon the Triassic [shales and limestones] or locally upon the Chitistone or the still older greenstone. From the ridge between Sheep and Copper creeks there is considerable cropping of the formation, which extends continuously to the divide between Rock and Strelna creeks, and again there is a considerable thickness in the high mountains at the head of the south fork of Strelna Creek.

As viewed from a distance the high ridge between the north fork of Kuskulana Glacier and the eastern drainage of the Kotsina appears to have a capping of sedimentary rock resting upon the greenstone, and though this region has not been visited it seems probable that the Kennicott formation may occur in these high peaks. To the east of the Kuskulana Glacier it first appears in the bed of Trail Gulch, at an elevation of about 2,200 feet, and may be traced eastward for a distance of about 3 miles. In this locality the formation affords

HEAD OF NIKOLAI CREEK.

Base of Kennicott formation in foreground; Chugach Mountains in background.

fossil remains. It does not appear again west of Lakina River, but to the east of that stream, in the drainage of Fohlin Creek, it attains considerable development, having a thickness which possibly reaches 1,000 feet or more. In this locality and in the last it seems as if the formation was deposited in a submerged valley, the sides of which had considerable height above the level of the water.

East of Kennicott River the Kennicott formation occurs at the head of Nikolai Creek, where its general relations to the topography and to the Triassic formations are shown in Pl. [V]. The sloping strata in the middle of the illustration are the sandstones of the basal portion of the Kennicott formation, while the deep trenches cut through them into the underlying limestone and greenstone. The mountains in the distance are composed of Triassic shales, with igneous intrusions, which have protected the mountains from erosion.

Beyond the Nizina the formation is found capping the shale ridge between Young Creek and the Chitina.

Age of Kennicott formation.—The age of the Kennicott formation has been definitely determined by Dr. T. W. Stanton, who has studied its fossils and proved their general correspondence with the fossils of the Knoxville formation of northwestern United States. This places the formation in the doubtful series lying at the top of the Jurassic or at the base of the Cretaceous. The following forms have been recognized:

Inoceramus eximius Eichwald?
Belemnites sp.
Halobia occidentalis Whiteaves?
Rhynchonella sp.
Pecten sp.
Avicula sp.
Aucella pallasi Keyserling?
Lytoceras sp.
Hoplites sp.
Olcostephanus? sp.
Gryphæa sp.
Sagenopteris sp.

Concerning *Inoceramus eximius* Doctor Stanton says:

"This form is represented by a single specimen collected on Chitty Creek. It may be distinct from Eichwald's species, originally described from Turkusitun Bay in Cook Inlet and referred by him to the Neocomian. Eichwald described three other species—*I. ambiguus*, *I. porrectus*, and *I. lucifer*—all belonging to one section of *Inoceramus*, from the same horizon in Alaska. The present shell does not agre perfectly with any of the figures, but it is most nearly like *I. eximius* and probably comes from the same formation. Similar forms occur both in the Jurassic and in the Cretaceous, but the evidence of the other fossils from this part of Alaska favors the reference of the Kennicott formation to the Jurassic."

Of the form referred with a question to *Halobia occidentalis*, Doctor Stanton says:

"The specimens agree fairly well in sculpture and general appearance with some of the figures of Whiteaves's species from the Liard River, and may be identical with it. They are, however, somewhat suggestive of *Hinnites linæusis*, from the Jurassic (?) of Siberia.

"*Sagenopteris* is a genus which occurs both in the Jurassic and in the Cretaceous, but the species is thought by Professor Ward, to whom it was shown, to be near a species occurring in the Jurassic of the Pacific coast."

Concerning the general relations of the fossils from the Kennicott formation Dr. Stanton observes:

"These fossils are all either Upper Jurassic or Cretaceous, with a suggestion of a somewhat younger age for a few localities. In the present state of knowledge, and with these small collections, it is not practicable to determine whether they represent one horizon or several. In my opinion, they probably

all belong to the Upper Jurassic, though subsequent work may show the contrary. The question is connected with the still unsolved problem of the exact boundary between the Jurassic and the Cretaceous in the *Aucella*-bearing beds of Russia, Siberia, and the Pacific coast region of North America. The *Aucella* occurring in the Copper River district appears to be referable to a Russian Jurassic species, but it is also quite similar to the Cretaceous form in the lower Knoxville beds of California. The few other forms are mostly undescribed species of types that occur both in the Jurassic and in the Lower Cretaceous."

POST-KENNICOTT DISTURBANCE AND EROSION.

After the deposition of the Kennicott formation the region seems to have been uplifted from its previous low position with reference to the sea and to have suffered a slight deformation, which gave rise in great part to the present slightly inclined attitude of the rocks that were deposited not long before its initiation. In respect to the amount of folding produced this uplift was of much less importance than the earlier disturbance which caused the folding of the Triassic formations. It seems to have been a regional uplift without very much of the deformation which comes from lateral pressure.

The uplift which followed the deposition of early Cretaceous time seems to have been regional in its extent, and may be supposed to have affected all of the area between the present Wrangell Mountains and the coast and to have raised a large continent from the waters of the sea. The limits of the uplift can not be determined, but it was followed by a period of erosion during which the streams that developed upon the new land surface were able to reduce the land very nearly to sea level.

Before the completion of this cycle of erosion a period of volcanic activity was commenced which very materially altered the character of the topography by the upbuilding of immense piles of lava and of volcanic tuffs.

COAL-BEARING ROCKS.

Two localities where coal-bearing rocks are known to be present lie within the area under discussion. One is situated on the high ridge between Hidden Creek and the heads of Bear and Fourth of July creeks, the other is near the head of Chitistone River. Little is known about either locality, and there is no evidence at hand on which a definite statement concerning the age of the beds may be based. The first-mentioned locality is approximately 2 miles north of the saddle known as Fourth of July Pass, through which the trail runs in crossing the ridge between Fohlin Creek and Kennicott Glacier. The area is small, possibly not over 20 acres, and lies at an altitude of nearly 6,000 feet. The beds are probably not much over 50 feet thick, and consist of black carbonaceous shales with thin coal seams overlain by arkose sandstone. The coal beds have a horizontal position and lie unconformably on the upturned edges of beds belonging to the Triassic limestones and shales. They adjoin the Chitistone limestone on the north and appear to pass over the great fault by which the Nikolai greenstone and the Triassic limestones and shales are brought in contact. A mass of andesite, with a spirelike

form about 50 feet high, rests on the coal-bearing rocks, but since its age is unknown it furnishes little additional evidence for the age of the coal. Coal is not known to be present in the Kennicott formation. The Kennicott, moreover, is believed to be older than the great fault, and since the coal beds, as previously stated, appear to cover the fault, it is suggested that the coal is probably Tertiary.

The Chitistone River coal-bearing beds were not seen by members of the Survey party, and their relations to the other formations are not known. From the reports of prospectors it is thought that the coal beds are thicker, more extensive, and more folded than those of the area just described, and it is possible that they may be of different age.

TERTIARY VOLCANIC SERIES.[a]

Description and occurrence.—In the region about the head of Nizina River, extending westward to Mount Blackburn and eastward into the Skolai Mountains, there is a series of bedded volcanic rocks made up of andesites, rhyolites, and strata of pyroclastic origin. The main distribution of these rocks is in the region which was not penetrated during the explorations of 1900, but a sufficiently extended view of the upper basin of the Nizina was obtained to indicate the relations which the series bears to the older sedimentary and igneous rocks. The character of the materials is shown by the débris occurring upon Nizina Glacier. A single outlier, which is undoubtedly to be correlated with the series, lies north of the trail opposite the pass east of Kuskulana River. * * *

Standing upon the high, shaly ridge between McCarthy Creek and Nizina River and looking toward the north and east, one sees that the black Triassic shales, with the massive Chitistone limestone beneath them and the greenstone still underlying, are folded in broad arches or domes, and that these structures have been eroded to a general uniform surface, and upon this surface a series of rocks has been nonconformably deposited. Assuming, as seems allowable, that these rocks were deposited in a nearly horizontal position, it is evident that there has been some deformation since they were laid down, as there is a general dip of the stratification toward the north, so that the series rising toward the south and east disappears where the underlying formations come up to form the tops of the range. Volcanic rocks, the description of which answers very well to that of this series, were mentioned by Rohn as occurring in the region at the head of the Nizina and the Tanana, also along the northern edge of the St. Elias Range; and an important volcanic series on Nabesna River has been described by Brooks.[b]

The rocks of the series are said to include rhyolite, andesite, and basaltic types. A similar series of volcanic rocks is known to occur along the northern front of the St. Elias Range.

Thickness of volcanic series.—No accurate determinations of the thickness of the volcanic series were possible, but from photographs showing its occurrence it is estimated that it can not be less than 3,000 feet in its maximum development.

[a] Schrader and Spencer, op. cit., pp. 51–52.

[b] Brooks, A. H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska, including a description of the copper deposits of the upper White and Tanana rivers: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 362.

Age of volcanic series.—In the description of the topographic development of the Copper River region it will be shown that the land surface which was produced through the process of erosion previous to the formation of the volcanic series had its origin some time during the Tertiary, and with this conclusion as a basis it may be concluded that the age of the volcanic series is also Tertiary. There is, however, no criterion for determining the exact portion of the period to which its formation belongs, though it is doubtless later than the Eocene. Brooks shows that the volcanics of the St. Elias Range are probably of Tertiary age.[a]

IGNEOUS ROCKS.

Preliminary statement.—The igneous rocks of the Kotsina-Chitina area, as has been stated, include gabbro, diabase, diorite, andesite, granite, and rhyolite. They have not been studied in an exhaustive way and the following descriptions are general. The various rocks are grouped in the description according to their occurrence in the larger geological divisions of the sedimentary rocks. Areas of igneous rocks are not represented in a detailed way on the map (Pl. II). Diorite and granite are not separated from each other, but they are distinguished from gabbro.

The intruded rocks of a porphyritic nature are given a distinct color. Andesites also have a separate color, but no attempt is made to separate those of intrusive from those of extrusive character.

Granular rocks in the unmetamorphosed sediments.[b]—The intruded rocks which occur in the unmetamorphosed sediments of the Wrangell region . . . consist of gabbros, granites, and dioritic rocks, and in addition there is a large cross-cutting mass of andesite which forms Castle Mountain . . .

The gabbro in the Mount Wrangell district is confined, so far as known, to three small areas: One in the Kotsina region between Long Glacier and Kluvesna Glacier, another at the head of Nugget Creek north of Kuskulana River, and the third just above the forks of Strelna Creek. The rocks of these three localities belong to the same type, but show minor variations. The gabbro occurring in the vicinity of Long Glacier is a coarse-grained rock, consisting of a very basic plagioclase, probably bytownite, and augite in large irregular grains. With the augite there is a small amount of brown hornblende, which is probably original. Magnetite occurs in large grains. In the gabbro of Strelna Creek there is some interstitial micropegmatite which is probably of secondary origin.

A rock which is similar to these gabbros, but which has, in addition to the minerals which they contain, a considerable amount of brown mica, was noted in the vicinity of the crossing of the main Chitina and the Kotsina trails. Here, in the walls of the canyon, there is a coarse-grained granular rock made up of andesite, diallage, hypersthene, and a considerable amount of dark-brown biotite. The relations of this rock are rather unusual, since it is granular rock cutting glacial gravels.

The only granite which has been noted in the Wrangell Mountains is located somewhere in the drainage of the second Kotsina Glacier. Its presence is known only from a specimen collected from the moraine. It is a fine-grained rock composed of biotite with some plagioclase.

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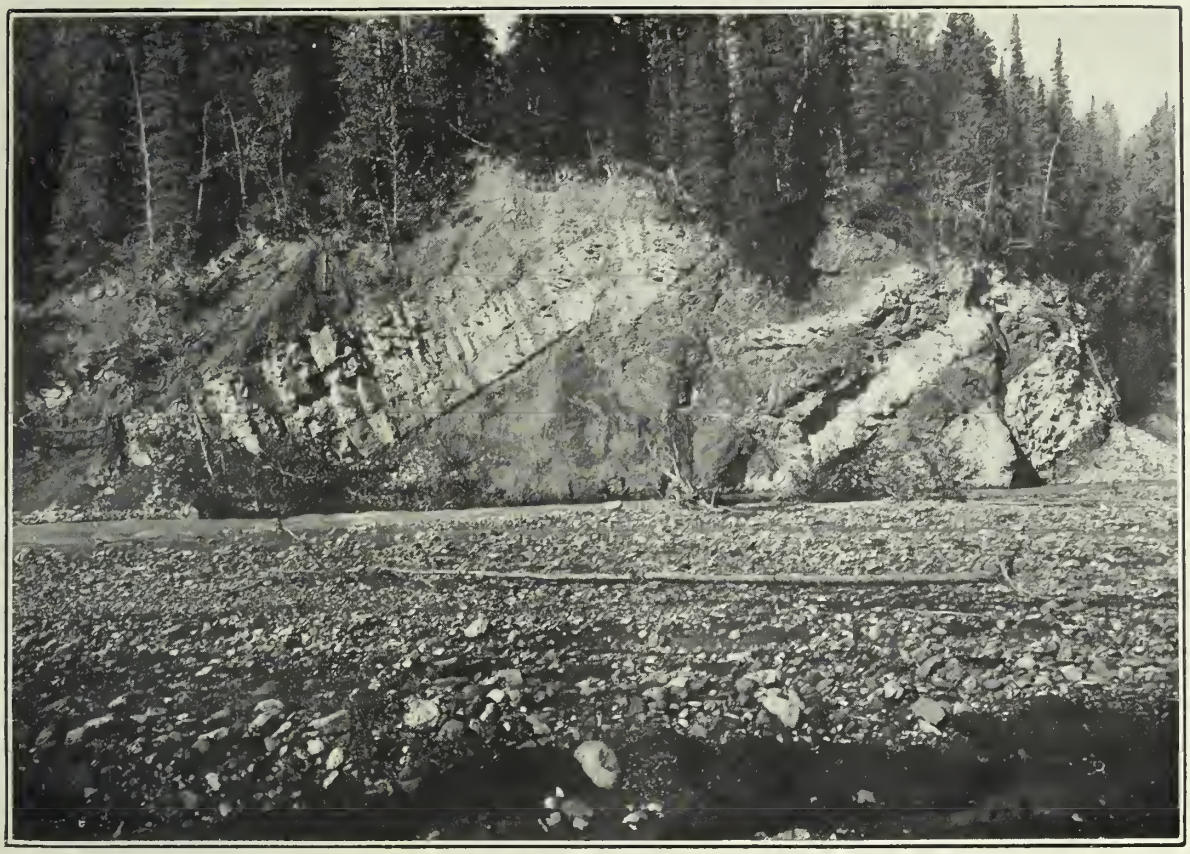
[a] Op. cit., p. 363.

[b] Schrader and Spencer, op. cit., p. 55 et seq.



A. INTRUSIONS OF FINE-GRAINED PORPHYRY IN BLACK SHALE ON YOUNG CREEK.

B. CASTLE MOUNTAIN.

Looking N. 60° W. from ridge between Gilahina Creek and Lakina River.

On the north side of the main tributary of Kotsina River, near Surprise Creek, there is a mass of diorite which varies considerably in character from place to place. In some parts the rock is practically granular, while elsewhere it becomes porphyritic. It is composed essentially of abundant thick prisms of plagioclase, which is probably andesine, while between these prisms there is a sort of groundmass composed of orthoclase and quartz. Biotite and hornblende occur in irregular grains and imperfect prisms. The rock is related to granodiorite, but may be called a quartz diorite.

A porphyritic phase of diorite occurs along the west side of Kuskulana Glacier, below the forks, though this mass has not been represented on the map. The broad dike which is represented as crossing the mountain mass between the forks of Kuskulana Glacier is supposed to have the same character.

Porphyries in the unmetamorphosed sediments.—Besides the granular or nearly granular rocks already considered, there is a considerable variety of porphyritic rocks occurring in dikes and irregular masses in the black shales of the Triassic formation and in the shales and sandstones of the Kennicott series. These rocks are rather generally distributed from the vicinity of Kuskulana River eastward as far as our observations extended. They are well shown in the shale series on either side of Kennicott River, and it is to the resistance which the intruded rocks have presented to erosion that the mountains of this vicinity owe their preservation. Some less important occurrences are observed in the valley of Young Creek and as far toward the south as Chitina River. Pl VI [*A*] is illustrative of dikes of fine-grained porphyry cutting the black shale in the walls of Young Creek.

On the map the intricate intrusion of the shales is represented in a diagrammatic way to indicate the character of the intrusions rather than the actual occurrence of the cross-cutting beds.

The porphyries of the class here under consideration are always much altered, so much so, indeed, that it is very difficult to determine their exact nature, but it may be seen that they are all not identical, though they are probably closely related throughout. They are mostly diorite or quartz diorite porphyries, judging from the aggregates of altered minerals which now make up their mass. They vary in grain from cryptocrystalline to porphyritic with stony groundmass.

These porphyries are, in part at least, later than the Kennicott formation, of Jura-Cretaceous age, for they are found cutting this series in the region between Lakina and Kennicott rivers, and dikes of porphyry cut the bedded volcanic series east of Kuskulana River, and in the Nizina region there are masses of unknown character cutting across the volcanic series. It appears that in general the intruded rocks have been injected at comparatively recent dates, although there are no data for determining the priority of one or the other of the different types of rock. It may be that the porphyries were intruded during the period of folding which preceded the deposition that took place in Jura-Cretaceous time, but so far as the evidence goes, it may be that they were introduced after the deposition of the Tertiary volcanic rocks.

Andesite cutting the Triassic.—The mass of Castle Mountain is composed of dark andesite, similar to that which forms the surface flows of the Wrangell region. On the western side of the mountain the contact with the shales and crumpled limestones may be clearly distinguished by the contrast between the dark-colored andesite and the sedimentary rocks which have been bleached and whitened through contact metamorphism. The appearance of Castle Mountain and the andesite contact is illustrated in [Pl. VI, *B*]. Looking at Castle Mountain from the southeast, one sees the contact running in a zigzag

course down the ridge on the left side, as shown in the picture, and again, with less distinctness at the right, which is at the base of the steep cliff.

Intrusive rocks in Tertiary volcanic series.—The occurrence of dikes of diorite porphyry in the volcanic series has already been noted, and aside from this the only knowledge of cross-cutting massive rocks has been gained from a distant view of the region lying east of the Nizina River, between Chitistone River and the first creek flowing into the Nizina. Above the foot of the glacier there is a mountainous mass, which shows the topographic characters that are common in the case of massive rocks, and this mass is in part surrounded by the flows and tuffs of the volcanic series. This occurrence is the only evidence of the post-volcanic date of the intrusive rocks, and it must be admitted as incomplete.

Andesite flows.—The recent lavas which occur on the southern and western slopes of Mount Wrangell are typical hypersthene andesites, composed of plagioclase, at least as basic as labradorite, much hypersthene in sharply outlined phenocrysts, and a small amount of augite. Olivine is sometimes present. The groundmass varies from glassy to finely crystalline. In color the andesites vary from red to gray and black, and in texture from vesicular to close-grained porphyritic.

The age of the andesite is Pleistocene and Recent. The form of Mount Wrangell is the result of successive lava flows, by which its cone has been constructed. The great sheet of andesite to the north of the Kotsina drainage lies above the mass of the Pleistocene, but gravels are found resting upon it locally, and glacial scoring is also observed, so that at some time since the most important outflows glaciation must have been more extensive than at present.

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Below Tonsina River, on the east side of the Copper, the river banks have a height of 400 to 600 feet, and here they are composed very largely of till. Here, also, andesite occurs in the upper part of the deposit, and this occurrence appears to be the western extension of the general sheet of andesite which may be found at intervals and traced toward the east, becoming of more importance as the mountains are reached. East of the trail leading from Tonsina to the upper Chitina the andesite is of considerable importance, and here gives rise to a prominent bench, which may be traced northward to the point where it connects with the andesite already mentioned as occurring on Chetaslina River, and from this point still northward, forming a marked terrace for a distance of at least 10 miles. Wherever observed there is evidence that the andesite was poured out during the glacial epoch. The greatest thickness of the glacial deposits is below it, but in protected places it always shows surfaces which have been smoothed by ice action, and there is no considerable area of the andesite exposed that does not carry exotic bowlders upon it. Locally there is also a considerable amount of gravel resting upon the andesite. This relation may be seen on Copper River in the vicinity of Billum's, and also at the crossing on Kotsina River.

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The edge of the lava flow forming the plateau north of the point at which Kotsina River emerges from the mountains seems unquestionably to have been in contact with the side of a glacier which extended outward from the upper valley from the time of the eruption. The same conditions may be suggested along the north side of Long Glacier.

The distribution of the andesite as represented on the map is only approximate, and underneath the latest gravels the lava undoubtedly has a much greater extent than is indicated, and over much more of the area where it is represented gravels may be found above it.

Just north of Long Glacier the thickness of the andesite is several hundred feet, while at the edge of the flow, in the neighborhood of Chetaslina River, it is less than 150 feet, and where it reaches Copper River and at the crossing of the Nikolai [Nizina] trail on Kotsina River it is less than 50 feet.

FAULTS.[a]

Displacements of the formations occurring in the Wrangell region are not at all infrequent, and while the faults are usually of small importance structurally, they are frequently followed by mineral-bearing veins. An example of this is seen in the Nikolai vein, which follows a fault having a throw of several feet. Two faults of very considerable importance have, however, been recognized where they cross Nizina River, while, from the observed relations of the various formations, a third break is supposed to exist in the Kotsina region. On the west side of Copper Creek the Chitistone limestone is found dipping toward the west and overlying the Nikolai greenstone in its normal position, while on the east side of the creek the greenstone comes in contact with Triassic shales; and though the relations of the former were not studied sufficiently in detail to allow the representation of the fault on the geological map, a break has been shown in the geological cross section in accordance with the hypothesis of a fault.

There is a fault crossing Nizina River about 3 miles above the mouth of Chitistone River, and, though its occurrence was noted, no opportunity was afforded for a detailed examination. This feature was observed by Hayes in 1891 and described as an over-thrust fault having a displacement of over half a mile.[b] The representation of this fault on the geological map must be taken as only approximating the actual relations.

The most prominent fault which has been recognized is the one which limits the southern extension of the greenstone as it crosses Nizina River. Here the shales of the Triassic are brought against the Nikolai greenstone, and, though the actual fault plane was not observed, it is seen from the horizons which come in contact that the displacement must amount to 3,000 or even 4,000 feet. East of Nizina River the continuance of the break is not known, since the region was not visited, but toward the west it probably extends for a considerable distance, and on the east side of Kennicott Glacier the displacement must still be in excess of 3,000 feet. The fault was also observed on the west side of Kennicott Glacier, and from this place it is probably continuous to Lakina River, where there is a displacement of several hundred feet. In age this great structural break antedates the deposition of the Kennicott formation, and its production probably belongs to the post-Triassic period of uplift and deformation.

PLEISTOCENE AND RECENT DEPOSITS.

Introduction.—Under the heading of Pleistocene and Recent deposits is given a general description of the unconsolidated deposits that now occupy the valley portions of the Chitina and Copper rivers and their tributaries as included in the area shown on the geologic map (Pl. II). The scale of this map is too small to give a detailed representation of the deposits, but their general distribution is well shown.

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[a] Schrader and Spencer, op. cit., p. 62.

[b] Hayes, C. W., An expedition through the Yukon district: Nat. Geog. Mag., vol. 4, 1892, p. 141.

Present features.—A view of the river valleys of this region discloses two very distinct topographic features, caused by two equally distinct geologic processes that have dominated the development of the topography during Pleistocene and Recent time. These features are very forcibly impressed on anyone who may have occasion to visit the region. The first is the present-day aspect of the accumulations of a former period of very rapid deposition, the completion of which was the closing event of the Pleistocene period. In their broad surface characteristics these deposits have changed but little since they were laid down. The second is the recent trenching by streams that is so marked a feature of late drainage activity in many other parts in Alaska also and that is brought particularly to notice where streams have worked upon unconsolidated deposits of Pleistocene age. (See Pl. VII, *A*.) This trenching began with Recent time and results from conditions that still prevail.

The completed result of Pleistocene deposition is presented to-day in the form of gravel and silt plains that extend over all the lower areas. They floor the large main valleys almost completely and extend up the tributary valleys considerable distances into the mountains. Their surfaces slope gradually in two directions—from the sides of the valleys inward to the lower levels occupied by the draining streams, and from the heads of the valleys toward their outlets. They are characteristic valley plains.

The combined ice and water drainage of Pleistocene time, that brought down such vast quantities of rock material from the surrounding mountain ranges, filling the valleys and spreading it out in the form of the gravel plain, has had its gradients and its relation to sea level changed by a widespread elevation which was differential rather than harmonious. The present rivers, in working down to the new grades thus imposed, have cut deeply into the Pleistocene plains (Pl. VII, *A*), so that to-day all the streams occupy trenches in the filled valley floor. Thus the valleys are incised from 50 to 600 feet into the unconsolidated Pleistocene deposits, and in many places through them.

Pre-Pleistocene land surface.—To understand more fully the distribution and thickness of the unconsolidated Pleistocene deposits it may be well to indicate briefly what the appearance of this region must have been just before the deposition of the Pleistocene began. This appearance may be imagined from an understanding of the present surface. To-day the country is especially characterized by rugged mountains, most of them showing well up on their sides the effects of vigorous glacial erosion. The sides are steep and in many places descend abruptly to the valley bottoms where the bed-rock slopes disappear beneath the comparatively flat Pleistocene deposits.

The bed-rock contour of the larger tributary valleys of the Chitina to-day present wide U-shaped cross sections typical of strongly

A. PLEISTOCENE GRAVEL BLUFFS.

North bank of Chitina River, above mouth of Nizina River, looking northwest.

B. CHITISTONE LIMESTONE, NORTH SIDE OF ELLIOTT CREEK NEAR DECEPTION CREEK.

Nikolai greenstone below; Kennicott limestone above.

glaciated valleys, though the bottoms are now hidden in many places to a depth of at least 500 or 600 feet by Pleistocene deposits. Before the glaciers occupied them the broad valleys were no doubt essentially of the uniform deeply eroded rock-floored type, presenting rolling surfaces with here and there considerable hills rising from them, and encircled by high rugged mountains. At that time the mountains had not been glaciated and were not so steep sided, and the valleys were cut deeply only by stream erosion. Even in the main valleys of the Chitina, of the Copper just north of Taral, and of the lower half of the Kotsina, the rock floors were not flat, but presented rolling surfaces, for to-day there are considerable hills of hard bed rock standing above the more level unconsolidated Pleistocene deposits that surround them, like islands in a body of water. The general attitude of these bed-rock islands indicates that the pre-Pleistocene grade of the Chitina Valley was not as steep from the head to its mouth as it is to-day, for the areas of the older bed-rock surface exposed above the unconsolidated deposits are of considerable extent near the mouth of the Chitina, and are less exposed up its valley, where they are more deeply buried by the gravel and are only shown where the main stream and its larger tributaries have cut through the unconsolidated sediments.

The work of Pleistocene time was the filling of these valleys by vast quantities of poorly sorted material eroded by ice and water from the mountains that surround them. The old drainage of the valleys was overwhelmed by an invasion of glacial ice, and erosion and deposition by this ice and its attendant streams left the surface almost as we see it to-day. These unconsolidated deposits are the evidence that tell of Pleistocene time and its activities.

Erosion and deposition during Pleistocene and Recent time.—The Pleistocene and Recent geology of this region is probably brought most conspicuously to our notice by its unconsolidated deposits, but the erosional effects are also marked. The character and extent of the deposits are a direct result of the character and extent of the drainage of that time, and these were dependent on the character of the precipitation. It is not necessary to suppose a larger supply of moisture or a greatly different climate from that of to-day, but the form of precipitation must have been such as to give a great increase in the development of the snow fields that fed the glaciers and their streams. A great change in the character of the drainage appears to have come over the region at the beginning of Pleistocene time. This change involved a marked development of glaciers and their attendant streams, together with the greater rapidity of erosion and more active transportation of rock material that accompanies such phenomena. The growth of this kind of drainage seems to have

been rapid, until it finally dominated the whole area of the Copper-Chitina region. It apparently had various stages of advance to its maximum extent and then stages of decrease to its present condition. The present character and extent of glaciation is well shown on the map. The detailed stages of its advance have been largely obliterated by its retreat, but the evidences of its greatest development are still distinct, and a detailed study no doubt would bring out much of the history of that period.

Chitina Valley appears to have been occupied by a great valley glacier, and its tributaries, especially the Nizina, Kennicott, Lakina, and Kuskulana valleys—the principal feeders of the master ice stream on the north—were also filled by ice streams that united in the great Chitina Glacier. In addition there were smaller glaciers flowing into the Chitina from the south. The glaciers from the head of Kotsina Valley, together with the Kluvesna and Long glaciers from Mount Wrangell, united with each other and their combined ice stream extended at least to the point where the valley opens out into Copper River basin. Thus it will be seen that this region at some time during the Pleistocene was practically hidden under snow and glacial ice. Only the higher mountain ridges protruded above it, yet even these were the gathering places for snow that fed the glaciers below. As the ice streams moved slowly, but powerfully, down their confining valleys, they were loaded with vast quantities of rock material which they carried with them to the lower level. How long the maximum extent of the ice invasion was maintained is not known, but when the glaciers had reached their greatest development and their increase was stopped by the lack of sufficient snow at their sources to balance the waste by melting at their lower levels, their retreat began. As the melting proceeded and the lower limits of the glaciers withdrew up the valleys, a great quantity of morainal material was dumped on the valley floors, and the water from melting ice spread this heterogeneous assortment of rock material over the valley flood plains, left bare by the receding glaciers, thus forming the valley-plain deposits almost as they are seen to-day. Melting of the ice did not proceed at a uniform rate, nor was it a continuous course of recession. There were intervals when melting was not so rapid, and then terminal moraines were laid down which the streams issuing from the ice front were unable to spread out in a uniform manner. There were times also when the ice readvanced over areas it had formerly occupied and laid down till sheets of greater or less extent on the unconsolidated partly sorted sediments. Terminal moraine heaps to-day occupy considerable areas in the valley plains and mark positions of halting in the recession of the glaciers to their present positions. Till deposits also occur on top of sediments that were laid down in bodies of quiet water after the first retreat of the

ice, in order to occupy their present positions in relation to the sediments they overlie, they must have been formed by a readvancement of the ice.

Character of the valley-plain deposits.—The unconsolidated deposits laid down during the recession of the ice are of various kinds. With few exceptions, they are all sediments of pronounced glacial character and present all the great variety of phases of such deposition, from the unsorted morainal dumps of bowlders, with many angular blocks, to partially sorted cobble beds, regularly arranged gravels, and coarse cross-bedded sands, and in many places considerable areas of typical lacustrine sediments consisting of fine sands and silts. Mendenhall[a] has described the character of these deposits in the Copper River Valley, and his description applies also to their continuation in the Chitina River valley:

> Such deposits are generally separated into (1) stratified or assorted drift, and (2) unstratified or unassorted drift, the first having been laid down under the influence of water, and hence showing a more or less stratified condition, while the second, deposited directly from the ice, consists of heterogeneous aggregates of coarse and fine materials without evident marks of stratification. The two forms are not always readily separable, nor are their relative positions always the same, either one occurring uppermost, and not rarely they alternate with each other several times between the surface and the bottom of the drift.

The greater part of the deposits that fill the valleys do not show the characteristics of gravel and sand laid down in standing water. Their deposition was governed by more or less local conditions of glacial and stream transportation and deposition, and these conditions each had its particular features in different localities that changed rapidly from time to time. On the whole, the peculiarities of deposition were a rapid dumping of material, much of which was coarse, into the ample valley basins, and a vigorous fluviatile grading of these materials in the lower areas of the valleys. Each tributary valley furnished an amount of material commensurate with its size and the ability of its stream to transport material out into the larger valleys, where the combined drainage net spread out and graded it all into more even surfaces but was inadequate to do the work of distributing it in uniform stratified deposits of any considerable extent, as might have been done if the deposition had been dominated by a large body of water, such as a lake.

There are, nevertheless, lacustrine deposits consisting of fine stratified sediments occupying more or less restricted areas throughout the valley drift deposits, which show that local lakes of greater or less extent existed in the main valleys, while the streams of tributary valleys were contributing their deposits of heterogeneous material.

[a] Mendenhall, W. C., Geology of the central Copper River region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1905, pp. 64–74.

The outflow of andesitic lava indicated southwest of Mount Wrangell on the geologic map (Pl. II) occurred after a large part of the Pleistocene deposits had been laid down, as is shown by the fact that it overlies a considerable thickness of these sediments. This relation has been examined by Schrader and Spencer[a] along Chetaslina River. They also noted a deposit of fragmental volcanic material in the sediments directly underneath the lava, which they associate with this outburst of volcanic activity. This fragmental material shows every appearance of having been ejected from craters in the form of bombs only a short time before the outflow of lava began. Fragmental volcanic material of this nature was observed by the present writers in the benches of Pleistocene sediments of the Kotsina Valley opposite the mouth of Roaring Creek. At this locality there is no lava overlying the material, but the bomb-like fragments have a rough stratiform arrangement under about 30 feet of gravels and silts. The bombs at this locality have a porous friable texture, and occur as roughly spherical masses from a few inches to a foot or more in diameter.

After the outflow of lava had taken place the area was again overridden by the glacier, as is shown by the fact that the surface of the lava has been smoothed by moving ice, and deposits of glacial débris lie upon it.

ECONOMIC GEOLOGY.

GENERAL STATEMENT.

The mineral resources of the Chitina and the Kotsina River valleys that are of present commercial interest are gold, copper, and possibly coal.

Gold has been mined from the Nizina placers since 1902. As in many other placer regions, however, no records of the early production are available, and no attempt is here made to give even approximate figures for the yield of gold in these six years. Gold placer mining is now on a more firmly established basis than in the past, and doubtless an increase in the yield of gold will be seen in the next few years. Possibly this yield may be increased further by an extension of the producing area as the conditions for economical mining grow more favorable.

Copper, because of the high price of that metal from 1905 to 1907, has received much attention from prospectors and others interested in copper production, but this region has not yet produced a pound of copper in a commercial way.

The coal deposits of Chitina Valley are probably of only local interest. No coal comparable in quality with the coal of Controller

[a] Schrader, F. C., and Spencer, A. C., op. cit., p. 59.

Bay or Matanuska River has been found, yet, if obtainable in proper quantity, the Chitistone River coal may have a small local demand.

At present, then, the Kotsina-Chitina area has an actual production of gold and a prospective production of copper, but, without detracting in any way from the importance of its gold placers, it may be said that the future position of the region as a producer of mineral wealth may be determined in large part by the importance which its copper deposits assume on development.

In this paper greater attention is given to the copper deposits. It is hoped that the facts observed are presented impartially and in such a way as to give a proper idea of the type of ores occurring here and of the progress in developing them since they were last visited by members of the Survey. Those seeking information in regard to the commercial value of the deposits described may be disappointed in finding no definite statement in regard to values. It has become the established practice in the Alaskan investigations of the Geological Survey not to treat this subject, for it evidently falls within the province of the mining engineer who investigates a particular property. In the short time available for their study it would obviously be impossible for the Survey geologists to sample the deposits visited, and it also appears unwise to publish the results of assays furnished by property owners, because it is not always possible to learn how a given sample was taken. It is admitted that the descriptions are in no way exhaustive. This is necessarily so from the conditions under which the work was done. In the first place the copper properties are all prospects and not developed mines. The ores examined are near the surface and are exposed in shallow open cuts or in short tunnels, so that there is little data at hand for determining the character of the ore in depth or for obtaining an accurate idea of the form of the ore bodies. In the second place time was too short to make a thorough examination of all the properties in the region. A few prospects were not visited because their locations were not definitely known, and in the absence of the owners either they were not found when searched for or it did not appear to be in accord with the best interests of the work to spend time in looking for them.

The omission of the name of a claim in the descriptions to follow, therefore, reflects in no way on the value of that claim. On the other hand, in a few instances where there was more than the usual opportunity for studying the ores it is possible that the more nearly complete descriptions of them will make it appear that they were considered to be of unusual promise or value. These more detailed descriptions, however, are given in the hope that they may lead to a better understanding of the copper deposits by the reader and enable him to draw his own conclusions respecting the character of the ores. Knowing

the harm that sometimes is caused by premature or hasty conclusions the writers have endeavored to state facts rather than inferences in the hope that more detailed and thorough studies may be made in the future.

COPPER.

THE COPPER MINERALS.

Preliminary statement.—The copper minerals most common in this region are not many. Those associated with the copper are even fewer. The copper deposits, therefore, so far as their mineralogy is concerned, are not complex, but it is difficult with the data at hand to give an outline of their history that is fully satisfying. Copper was seen in greatest amount as chalcocite, bornite, and chalcopyrite. Native copper should probably be mentioned after these. Malachite is the most noticeable of all the copper minerals. Azurite, cuprite, chalcanthite, and tenorite occur locally. Calcite, quartz, and epidote are associates of the copper minerals in some places.

Descriptions of all the minerals named are to be found in any book on mineralogy, but for the convenience of those who may not have such books at hand their chemical composition and percentage of copper will be given in describing the copper minerals as they occur in this region.

Native copper.—Native copper is found in the Nikolai greenstone in many places. It is believed to be entirely of secondary origin, and occurs most commonly either without quartz in the amygdaloidal lava flows or accompanied by quartz, or quartz and epidote, in small veins or shattered portions of the lava flows. It appears to prefer the amygdaloidal phases of the greenstone rather than the more compact beds such as the coarser grained diabase lying immediately below the Chitistone limestone, yet native copper is found there also. It takes the form (1) of small grains and slugs formed by alteration or replacement, or deposited in cavities which were either produced when the lavas solidified, or else resulted later from solution, and (2) of thin crumpled leaves or films deposited along fractures resulting from strains and movements in the rock. In places the copper forms small lenticular veinlike masses, or it occurs as a network of intersecting seams almost like the complex of quartz veins sometimes seen in a rock that has been brecciated and recemented. This last phase is particularly common where the copper, accompanied by quartz, has filled cavities in the country rock. When such a mixture of quartz and copper is struck with the hammer so as to shatter the more brittle quartz, it leaves a cavernous or spongelike mass of copper. That the copper has in some places filled open cavities seems to be shown by the presence of perfectly formed quartz crystals in it. In at least one place native copper is restricted to a particular lava flow and is not seen in the flows lying immediately

above and below. At this locality it is associated with a black glassy amygdaloidal filling consisting of a mixture of copper oxide and carbonaceous matter. The copper is present as grains and films in the amygdules and also in the greenstone. No quartz was seen here, but it was reported that a mass of copper and quartz weighing 60 pounds was taken from an outcrop only 400 or 500 feet distant. This is the largest piece of native copper found in place reported to the writer.

Native copper is found in the gravels of several streams, such as Nugget, Dan, and Chititu creeks. The largest piece yet discovered is on Nugget Creek. It is estimated to weigh between 2 and 3 tons. Native copper is common in the gravels of Dan and Chititu creeks, the pieces ranging in size from small grains to masses of 300 pounds weight. The copper is all more or less rounded and some of the pieces assume most fantastic shapes. Native copper and native silver crystallized together in the same nugget are not uncommon. As a rule the placer copper is nearly free from quartz, but is considerably oxidized, and some pieces when broken are found to be spongy or cavernous. Native copper was not seen in the Chitistone limestone.

Cuprite.—The dark-red oxide of copper, cuprite (Cu_2O, 88.8 per cent copper), is found in the Chitina region, where native copper is found, and usually does not occur without it. It is difficult or perhaps impossible to determine whether the native copper results from the reduction of the cuprite or the cuprite from the oxidation of the copper. Probably both changes take place. Cuprite is not known in the Kotsina-Chitina country in quantities sufficient to make it of value as an ore. Many of the placer copper nuggets show little crystals of cuprite when the oxidized scale is broken from the surface. Cuprite is also seen as little red specks in copper-bearing greenstone or on the native copper in the greenstone.

Tenorite.—The black oxide of copper (CuO, 79.8 per cent copper), tenorite or melaconite, is of rare occurrence in this region. Together with a certain amount of carbonaceous material it forms a black, glassy or resinous filling of cavities in some of the amygdaloidal lava flows. It also was found in one place in association with the quartz of a small vein filling.

Chalcocite.—The cuprous sulphide, chalcocite, frequently called copper glance (Cu_2S, 79.9 per cent copper), forms the most valuable of the known copper deposits of Chitina Valley. It is found in the Nikolai greenstone at many places from Kotsina River to the Chitistone, but its greatest deposits are in the Chitistone limestone. It is more abundant in the eastern part of the field than the western. In the greenstone it forms irregular lenticular and veinlike bodies, replacing the rock, or is disseminated through it in small particles. In places it is associated with epidote. Large masses of practically pure

chalcocite were formed in the Chitistone limestone by replacement of the original rock. It is unoxidized save for a thin film on the surface, and breaks with a smooth, shining fracture, like stove polish. Both here and in the greenstone it may more probably be of secondary origin, but from what original mineral it is derived is not known.

Bornite.—On the whole, bornite (Cu_5FeS_4, 63.3 per cent copper) is perhaps the most widespread copper mineral of the region. It is found in the greenstone and in the limestone near the limestone-greenstone contact, but it is much more common in the greenstone. The bornite usually occurs without accompanying minerals other than those of the altered greenstone. It is also seen, however, accompanied by calcite and a minor amount of quartz in veins. In the greenstone it assumes practically the same form as does chalcocite, that is, it is disseminated in grains through the rock or occurs in it in irregular veins or lenses. Sheared portions of the greenstone in places show a mixture of more or less replaced country rock and nearly pure bornite. Thin sections of the ore show that the greenstone, while it appears in the hand specimen to be quite fresh, is nevertheless highly altered and contains much secondary calcite. In some thin sections the ferromagnesian minerals are practically lacking. The bornite is scattered through the rock in small grains that are in places intergrown with chalcopyrite. This intergrowth of bornite and chalcopyrite on a much larger scale is usual in the vein deposits accompanied by a calcite gangue.

Chalcopyrite.—So far as prospecting has shown, chalcopyrite ($CuFeS_4$, 34.6 per cent copper), is not an abundant copper mineral in the region under discussion, but it accompanies bornite in a great many places, forming an intimate intergrowth with it. It may not be distinguishable in a hand specimen, but many of the thin sections examined under the microscope show it to be present. Where chalcopyrite and bornite are accompanied by calcite in vein deposits the two minerals crystallize in larger masses than in the greenstone, and with the white calcite background they form a handsome ore. It is natural to expect that the rich sulphide deposits may have been derived from poorer pyritic ores, and proof of this was sought, but no conclusive evidence on this point was discovered.

Malachite.—The green copper carbonate, malachite ($Cu_2(OH)_2CO_3$, 57.5 per cent copper), forms a stain on the copper minerals and on the inclosing country rock wherever copper is found. In most places it is conspicuous in a degree entirely out of proportion to the quantity of copper present and is apt to give one a greatly exaggerated idea of the deposit it marks. Malachite forms a green film that covers exposed surfaces of ore and rock and penetrates along joint planes and fractures wherever the copper-bearing waters find an entrance. Though it is the most widespread and noticeable of

all the copper minerals, it is not known to be present anywhere in the region in sufficient amount to make it of importance as an ore. In a few places it forms small deposits in broken limestone. Weed [a] in describing this mineral says: "Owing to its brilliant green color a very small amount will stain a very large amount of rock or vein matter, or color thin and worthless incrustations or nodules of valueless material, so that it is difficult and, in fact, often impossible to form any accurate opinion of the ore from its external appearance."

Azurite.—The blue carbonate of copper, azurite ($Cu_3(OH)_2(CO_3)_2$, 55.3 per cent copper), is much less common in this part of the Copper River region than malachite. It is found chiefly in connection with deposits of chalcocite in limestone, and in places is clearly an alteration product of the chalcocite. At the Bonanza mine azurite forms small veins or veinlets in joints or fractures of the limestone around the boundaries of the main ore body. Some of the veins when broken show a core of chalcocite. Azurite also forms beautiful deep-blue crystals on the chalcocite. On the whole, it may be said to be an uncommon mineral in this region and is rarely seen as an alteration product of the ores in greenstone except where they are accompanied by calcite.

Chalcanthite.—The blue copper sulphate, chalcanthite ($CuSO_4 5H_2O$, 25.5 per cent copper), was observed in a few places where water seeping from the copper-bearing greenstone had evaporated, leaving small crystals of the sulphate on the rock surface. It is easily recognized by its appearance and acid taste. It is of no importance as a copper ore in this region.

OCCURRENCE OF THE ORES.

General statement.—The copper ores of the region are associated with the Nikolai greenstone and the Chitistone limestone. Copper is widely distributed through the greenstone, but the largest and most valuable of the known deposits are in the limestone very close to the limestone-greenstone contact. Copper, however, was not seen in the Chitistone limestone at any considerable distance above the greenstone; that is, the copper minerals found in the limestone can be shown in almost every instance to be near the base of the formation and consequently near the greenstone. All of the important known deposits in limestone are in the eastern part of the district. The deposits in greenstone, on the other hand, do not appear to be more developed in one locality than in another.

The copper ores may be referred to one of the three following classes: (1) Copper and copper-iron sulphides associated (*a*) with

[a] Weed, W. H., The copper mines of the world, p. 30.

greenstone and (*b*) with limestone; (2) native copper associated with greenstone; (3) placer copper.

On the basis of form the first class, and to a certain extent the second also, may be divided into (1) vein deposits and (2) deposits of irregular shape to which the name "bunch deposits" has been applied. Under veins are included the deposits of tabular form. In nearly all places observed they are clearly associated with fault planes or shear zones, and are accompanied by the vein minerals calcite and quartz, with epidote also present in some places. Ore bodies of this nature approach more nearly to the geometric form commonly ascribed to "fissure veins."

Regularity and definiteness of outline, however, are not characteristic of the Kotsina-Chitina ore bodies. In by far the greater number of places they have an irregular form that Mendenhall has described under the term "bunch deposits."[a] This term is not entirely satisfactory, but it probably describes as closely as any one word the form of ore body most common in the Kotsina-Chitina region. It does not necessarily imply a mass of ore composed of copper minerals alone, since most of the ore bodies to which the term might be applied are not such masses, but it does suggest an approach to something like equality in the dimensions of the ore-bearing rock mass, and especially it conveys an idea of separation of one body from other bodies.

It has already been pointed out that faulting is common in the rocks of the Wrangell Mountains. Some of the faults are of great displacement, but most of them are small. Crushing and shearing are slightly different expressions of the same disturbances that produce the faulting. Openings produced in this way have given opportunity for extensive circulation of waters that carried and deposited copper minerals. Most of the channels must have been exceedingly variable in form and direction, because regularly formed and clear-cut veins are so rare in the region. This is particularly true of ore bodies in the greenstone.

Copper sulphide deposits in greenstone and limestone.—The copper ores in greenstone are prevailingly bornite with smaller amounts of chalcopyrite, chalcocite, and native copper in approximately the order given. In limestone the ores are chalcocite, bornite, and chalcopyrite. The surface oxidation product in greenstone areas is malachite. In limestone azurite is common as an oxidation product, but perhaps no more abundant than malachite.

Copper ores in the greenstone are composed in many places of country rocks and copper minerals without accompanying vein minerals. The copper sulphides occur in shear zones or in jointed and

[a] Mendenhall, W. C., Geology of the central Copper region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1905, p. 42.

shattered portions of the rock; they fill fractures in the rock and also occur as a replacement of it. As has been stated, bornite is the most common copper mineral in the greenstone, but chalcopyrite is probably always present with it. All the thin sections of bornite ore examined showed chalcopyrite in small amount. In some of the calcite vein deposits chalcopyrite is nearly, if not quite, as abundant as bornite. Chalcocite is seen in the greenstone in some places accompanying or accompanied by bornite, or by bornite and chalcopyrite, a relation suggesting the derivation of the chalcocite from the poorer sulphides. A careful examination of the ores in greenstone is usually necessary to determine the limit of impregnation, which is not marked by any definite boundary, the replacement becoming gradually less with increasing distance from the center of impregnation. In limestone areas, on the other hand, the transition from ore minerals to country rock is more abrupt and the boundary surface is more easily determined. Unfortunately deposits in limestone appear to be less numerous than those in greenstone. The large size of the chalcocite bodies in limestone and their comparative freedom from included fragments of the country rock, such as are always present in the greenstone ores, is probably due to the grater solubility of the limestone. There is a possibility also that some chemical quality of the limestone gave it greater precipitating power than was possessed by the greenstone and made it a more favorable place for deposition of copper minerals from solution. This, however, is offered merely as a suggestion, for it can not be proved with our present knowledge of the conditions during ore deposition.

Where copper minerals are associated with gangue minerals in veins the gangue is chiefly calcite, but is usually accompanied by a small amount of quartz. One of the striking features of the copper deposits throughout the region is the scarcity of quartz accompanying them. Veins of quartz and epidote are of local importance, but on the whole calcite is the prevailing vein mineral. Veins and stringers of calcite, as well as small grains of that mineral, are found throughout the greenstone, but are more abundant near the top. Part of the calcite may have been derived from the overlying limestone, but a second source of calcite is the basic feldspar in the greenstone. All the thin sections of ore in greenstone show a rock more or less decomposed in which secondary calcite is common. Although it would be difficult or impossible to prove that the calcite in a particular case was not introduced from other sources than the greenstone, the possibility that some of it has that origin is to be considered. So far as could be determined at the exposures, the veins of this kind that were examined are subject to rapid changes in thickness from place to place. Few of them were traced for any considerable distance.

This statement, however, is not to be interpreted as implying that they do not so continue. At several localities variation in the thickness of the veins is plainly due to faulting later than the ore deposition and oblique to the veins. Slight movements along such faults may either increase the thickness of the vein or diminish it according to the direction of the movement. It is perhaps safe to say that the effects of faulting will be one of the difficulties encountered in mining in this region.

Native copper associated with the greenstone.—Native copper is associated with amygdaloidal phases of the Nikolai greenstone and is also found accompanied by quartz or by quartz and epidote in veins cutting the greenstone. Most commonly it occurs as grains and small slugs in the amygdules and disseminated through the greenstone and as films or leaves and small veinlets cutting the greenstone. Tabular masses deposited in joint planes also occur and without much doubt indicate the way in which the large mass of native copper on Nugget Creek was formed. Such masses were not seen in place in Chitina Valley, but they have been found east of Skolai Pass near the head of White River. In a few places native copper occurs in amygdaloidal greenstone in association with a mixture of copper oxide and carbonaceous matter filling the cavities of the lava. Much of the native copper is probably secondary and is thought to have resulted from the reduction of previously deposited sulphides or oxides. What part, if any, is primary is a question which it is difficult to answer.

Placer copper.—Copper is present in stream and bench gravels in a number of localities, particularly on Chititu, Dan, and Nugget creeks. It is found in pieces ranging from the size of shot to masses weighing hundreds of pounds or even several tons. Native silver accompanies the copper, either in nuggets of silver only or united with the copper in the same nugget, showing that the solutions depositing the copper carried silver as well. The source of the two metals is not definitely known, but the native copper deposits in the greenstone are naturally suggested as a place from which they are most probably derived.

SOURCE AND CHARACTER OF THE COPPER DEPOSITS.

The wide distribution of copper minerals throughout the Nikolai greenstone leads to the belief that the copper has been derived from the greenstone and owes its present concentration to the action of circulating waters. No evidence at hand warrants either affirming or denying a more deep-seated source for some of the copper-bearing solutions, but the weight of evidence is in favor of a local source for the copper.

The occurrence appears similar in this respect to that of the Lake Superior copper deposits, in accounting for which Van Hise says:[a]

> In this region the only locality at which the ore has been found in paying quantities is at Keweenaw Point, and the productive district is at present confined to a very small area about Calumet and Houghton. Notwithstanding this fact, there is scarcely a locality in the Lake Superior region where the Keweenawan basic lavas occur in which small amounts of copper are not found. Almost every porous amygdaloid shows flakes of it. In many localities it is so abundant that extensive exploration has been undertaken with the hope of finding ore bodies, as, for instance, in Douglas County, Wis., Isle Royal, and Mamainse. But all these explorations have resulted in failure. To me the almost universal association of small quantities of copper with the Keweenawan lavas is the most conclusive evidence that these lavas are the source of the metal.

It is a noteworthy fact that the Kotsina-Chitina region has been one of considerable volcanic activity since the time when the Nikolai greenstone was poured out, as is shown by the large amount of igneous rocks present—porphyritic intrusives, Tertiary volcanics, and Recent andesite flows. Steam issues from Mount Wrangell at the present time. It seems that the presence of such heated rock masses must have greatly promoted the circulation and solvent power of water in the rocks, whatever the source of that water may have been. The formation of ore bodies would appear to be due to the migration of copper minerals taken into solution and redeposited in more concentrated form in favorable locations by water circulating through the greenstone.

The study of ore deposits in many other places has shown that in typical examples the character of the ore is not uniform from the surface to the lowest parts of the deposit, but that ore bodies may be divided into three zones, each of which has its own characteristics but is not sharply separated from the one immediately above or below it. These three zones are the upper zone of oxidized ore, the zone of enriched sulphides, and the lower zone of unaltered sulphides. In attempting to divide the copper deposits of the Kotsina-Chitina region, according to this arrangement, it is immediately seen that they do not fully correspond with the ideal case. There is no zone of oxidized ore in the deposits of this region, such as is commonly seen in many other districts. Oxidation products in nearly every instance are confined to a thin film on exposed ore surfaces or along fracture planes in ore that has not been exposed directly to weathering or in fractures in country rock adjacent to ore. This absence of an oxidized zone is general throughout most of Alaska, and is due to climatic conditions. Many of the large masses of copper minerals have been exposed directly to the weather for a long period of years, but the mechanical breaking down of the ore body and inclosing rock has kept pace with

[a] Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 1103.

or has exceeded the rate of chemical alteration. The talus slopes on both sides of the ridge at the Bonanza mine contain a large amount of unaltered chalcocite fragments derived from the outcrops of the ore body above. Float ore is present in streams, and either shows nothing but a thin surface alteration or is practically fresh.

It is desirable to determine, if possible, to which of the two lower zones the present ore bodies belong, whether they were deposited in their present form, and are therefore primary ore bodies, or whether they have resulted from alteration and enrichment of previously existing ore bodies, and are therefore secondary. This question is of importance because it will help in forming an opinion of the character of the ore bodies that may be found at depth. If those now exposed are shown to be secondary enriched ores, then it may be expected that the deeper ores will be leaner. If on the other hand they are primary, there is no reason to suppose that the deeper ores may not be as rich as those at the surface. To answer this question with confidence would require more time and closer study than it was possible to give. No deep workings have been made, and there is no evidence from that source concerning the probable character of the ore at depth.

It is nevertheless desirable to state such facts as throw any light on the problem. From studies of many ore deposits it is known that the ground-water level is an important factor in the consideration of veins whose original material has been modified by the action of surface water. Above the water table the vein, as well as the country rocks, are most rapidly affected by the ordinary processes of decay, and material is taken into solution by circulating water to be brought to the surface or to be carried downward and redeposited. By such solution and redeposition an enrichment of the lower part of a vein may take place. Such enrichment has been found to be more or less closely connected with the ground-water level and to a certain extent gives ground for the belief generally held that the richness of ore deposits increases with depth. The depth at which ground water is encountered varies in different districts and localities. In some regions it is found near the surface; in others it is not encountered until a great depth has been reached. From the evidence at hand it appears that the ground-water level in the region under discussion is near the surface in most places and in many places reaches it. Furthermore, mechanical breaking down of the ores and country rock is so rapid at present as to prevent the formation of an oxidized zone, and consequently of an enriched zone. It therefore seems improbable that secondary ores are forming or have formed under present conditions, but it is still possible that the ores may be secondary ores formed in a previous cycle when conditions were different from what they are now.

There are a number of facts that may be stated as having some bearing on the primary or secondary character of the ores. The evidence, however, is for the most part of a negative rather than a positive character and is consequently more or less unsatisfactory. All of the ores under discussion that are of possible economic value are secondary in the sense that they are concentrations from copper disseminated through the greenstone, possibly in the form of one of the two sulphides just mentioned or contained in some of the constituent minerals resulting on consolidation of the magma. Clarke[a] in discussing the relations of the several sulphide minerals of copper has stated that "chalcopyrite and bornite are probably the primary compounds from which the others in most cases are derived, and they have been repeatedly identified as of magmatic origin." It is, however, the primary or secondary character of the ore bodies themselves, irrespective of their original source, that is under discussion, and the following statements have reference to this question:

(1) All the copper sulphides that have been described are known to occur as primary minerals in ores, and the fact that a given ore is composed of bornite or chalcocite is not necessarily evidence of its secondary character.

(2) The absence of the leaner sulphides—chalcopyrite and bornite—in such chalcocite deposits as that of the Bonanza mine might be considered as presumptive evidence that the chalcocite was deposited primarily as such and not secondarily by the alteration and enrichment of an earlier ore body.

(3) In considering the ores in greenstone it should be stated that, while bornite is the prevailing copper mineral and in many places chalcopyrite may not be distinguished by the eye alone, yet nearly all of the thin sections examined under the microscope show it to be present either intergrown with bornite or surrounded by it. This is true of both vein and "bunch deposits" and suggests an alteration of primary chalcopyrite to bornite as being more probable than a simultaneous deposition of the two minerals.

(4) Chalcocite, although it is held to be primary in some localities, is usually considered a secondary mineral. In the Bonanza ore body chalcocite is practically the only mineral in the limestone. Neither chalcopyrite nor bornite was found in the ore. Yet immediately below the contact in the same shear zone bornite, chalcocite, and native copper are present in small amounts. If the sulphides in the greenstone are secondary, it appears more probable that the ore in limestone is secondary also.

(5) "Native copper is commonly, if not always, a secondary mineral, either deposited from solution or formed by the reduction of some solid compounds."[b]

[a] Clarke, F. W., The data of geochemistry: Bull. U. S. Geol. Survey No. 330, 1908, p. 568.
[b] Idem, p. 564.

If these facts are considered in the light of experience in other regions, they appear to favor a secondary rather than a primary character for the sulphide ores in greenstone, but they leave still greater doubt concerning the chalcocite deposits in limestone. No reason was discovered why any of the ore bodies examined should increase in richness and value with depth through any other cause than by an increase in the size of the ore body. It is believed that the surface indications in most places give a fair idea of the maximum richness of the deposits in so far as that richness depends on the character of the copper minerals resulting either from enrichment or from oxidation and removal in solution of minerals in the upper part of the ore bodies.

DESCRIPTION OF PROPERTIES.

Copper prospecting in the Chitina region is carried on from a few central localities, of which those receiving most attention are Kotsina River (including Elliott Creek), Kuskulana River, Kennicott River, and Chitistone River. These centers are named from west to east, in the order in which they were visited, and the prospects will be described in the same way.

KOTSINA RIVER BASIN.

Kotsina River receives a large part of its water from snow fields and glaciers on the southern slopes of Mount Wrangell and joins Copper River 2 miles above the Chitina. Much of the drainage area is occupied by Nikolai greenstone, but the limestone, shales, and conglomerate are all present. Prospecting is most actively carried on in the upper part of the basin and on Elliott Creek. The upper tributaries include Peacock, Surprise, Roaring, Ames, Rock, Kluvesna, and Copper creeks. No work has been done here which can properly be called mine development, as there is no place where sufficient work has been done to demonstrate the presence of a mine.

KOTSINA RIVER.

Practically the only prospecting on the Kotsina itself is that done by the Great Northern Development Company. This company is the largest one carrying on operations on the Kotsina, to which, however, its interests are not confined. The headquarters of this company are on the Kotsina River at the mouth of Roaring Creek, and its equipment includes a sawmill and telephone connection with the government telegraph line at Tonsina. Probably 100 men were employed during the summer. The prospects on the river include five short tunnels, the nearest of which is about one-half mile below the camp. They are within a short distance of one another on the south

side of the river and almost on the same level with its broad gravel floor. None of these tunnels had been driven farther than 20 feet in August, 1907. At the first tunnel a porphyritic dike 10 feet thick cuts a fine-grained greenstone. Its course is N. 30° W. and it is bounded on both sides by fault planes. A little copper-bearing pyrite was deposited along the faults in the fractured rock. At the second tunnel, a few hundred feet to the west, a quartz vein varying from 4 to 6 inches in thickness contained a little copper pyrite. The vein has a strike S. 50° W. and cuts the greenstone in a perpendicular direction. At the other three tunnels a little pyrite is present in the greenstone, and its oxidation gave the brown stain by which the tunnels were located.

AMES CREEK.

Ames Creek is the first stream below Roaring Creek on the south side of Kotsina River. It is a small stream in a hanging valley and like nearly all the tributaries of this river owes the broad round cross section of its valley to the work of glacial ice. The copper prospects include three tunnels, the property of the Great Northern Development Company, known as tunnels 6, 7, and 8.

Tunnel 6 is on the west side of Ames Creek, 1,400 feet above its mouth. Early in August, 1907, it had been driven 50 feet in a southwesterly direction in frozen slide rock from the hill above. Country rock in place had not been reached. About 100 feet above the tunnel a little pyrite is seen in a dense, hard, faulted greenstone.

On the east side of Ames Creek, 50 feet higher than tunnel 6, is tunnel 7, which runs N. 30° E. for 70 feet through loose slide rock before reaching the undisturbed greenstone, which here is fine grained and stained with iron from the oxidation of pyrite.

Tunnel 8 is also on the east side of Ames Creek, one-fourth mile south of tunnel 7. It has been driven for 30 feet in amygdaloidal greenstone, but no copper has been found.

ROCK CREEK.

Rock Creek is one of the largest southern branches of the Kotsina and heads against Strelna and Nugget creeks, tributaries of Kuskulana River. A horse trail crosses the divide from Rock Creek to Strelna Creek and is the shortest route from upper Kotsina River to Chitina Valley. Active prospecting was confined to Lime Creek, a tributary of Rock Creek, which joins it from the east. The Warner prospect, at the mouth of Rock Creek, which was visited and described by Mendenhall in 1902, is now patented and no further work has been done on it. Lime Creek flows near the limestone-greenstone contact, and the copper deposits, although mostly northeast of the creek on the opposite side from the southwestward-dipping limestone, are not far from it. The prospects are near the point where the Rock Creek

trail crosses Lime Creek. In July, 1907, a tunnel was being driven in the greenstone just below the limestone, only a few feet above the creek, but no ore had been found at that time.

Several hundred feet up the hill to the northeast was a tunnel 20 feet in depth in jointed greenstone. The principal copper mineral is bornite, which occurs in the greenstone as lenses or irregular lumps that have diameters from one to several inches. These patches, as far as the present surface shows, appear to be unconnected. Bornite also occurs filling fractures in the rock and forming small lenticular veins, but it appears principally in joint planes, on whose surfaces it forms a veneer that in places is an eighth of an inch or more in thickness. There are small veins of calcite and quartz.

About 50 feet farther east is an open cut showing similar rock and ore, although here the ore is in greater amount. The bornite occurs in sheared greenstone, cut by small faults striking N. 35° E. and dipping 60° S., and forms a lens-shaped mass 2 feet thick. The greenstone has nearly been replaced by bornite.

At a point 200 feet farther north and 100 feet higher is an open cut in amygdaloidal greenstone. The cavities are now filled with quartz or with a dark mineral, possibly chlorite. Several faults with gouge and zones of crushed rock up to 1 foot in thickness cut the greenstone with a strike of N. 15° E. and a dip ranging from 60° to 70° E. A little copper stain was seen along the crushed rock, but no other copper minerals are present, although bornite is found in the slide rock near by.

ROARING CREEK.

Roaring Creek is a southern tributary of Kotsina River, which it joins a short distance above the main camp. It heads in a small glacier and flows through an open valley several hundred feet higher than the level of Kotsina River. The country rock, except one small limestone area on top of the ridge between Roaring Creek and Peacock Creek, is greenstone, but the greenstone is not of uniform character, for slaty beds and hard, fine-grained, cherty-looking beds are intermingled with amygdaloidal flows. Most of the prospects are in the upper part of the valley.

The Great Northern Development Company has several prospects on Roaring Creek. One of these is located on the south side of a small gulch west of Roaring Creek near the camp known as camp 3. A tunnel was started in gray and black mottled slates near a fault plane which separates them from a greenstone mass. The strike of the slate cleavage and of the fault plane is the same, No. 20° W., and the dip is steep. The tunnel is perpendicular to the strike. There is some brown iron stain resulting from pyrite alteration, but no copper ore had been found.

Another tunnel was being started on the east side of Roaring Creek about half a mile above the tunnel just mentioned, but not enough work had been done to show the presence of ore. A piece of greenstone picked up near this place contained small particles of native copper.

Above camp 3, on the west side of Roaring Creek, a tunnel 50 feet long had been driven by the California-Alaska Mining and Development Company. This tunnel is 2,600 feet above the mouth of Roaring Creek and at least 1,500 feet above camp 3. The country rock is greenstone, and the ore consists of small calcite-quartz veins containing native copper and azurite. In the slide rock in a little gulch a few feet north of this tunnel, but some distance below it, a nugget of native copper was found, which was taken to Valdez and is reported to weigh about 800 pounds.

The Kotsina Mining Company[a] holds several claims on Roaring Creek. Among them are the Skyscraper and associated claims, located near the small limestone area previously mentioned. Several open cuts and short tunnels have been made, and in July, 1907, the company was starting a tunnel on an exposure of copper minerals 350 feet below the base of the limestone at the northern end of the area. This cut exposed a lenticular mass of chalcocite 6 inches thick and 3 feet long, as seen on the face, lying horizontally in the rough, coarse-grained greenstone that occurs immediately below the Chitistone limestone. In the vicinity are several greenstone exposures in which chalcocite forms small patches or lenses. They are seemingly in no way related to one another.

PEACOCK CREEK.

Peacock Creek joins Kotsina River about 2 miles below the more southerly of the several large glaciers from which the river receives its water supply. There are two branches of the stream, one extending toward the east and the other toward the southeast. The eastern branch originates in a small glacier, and the valleys of both branches were formerly occupied by glaciers. Greenstone is the country rock except for the limestone mass on the ridge between Roaring Creek and the more southerly branch of Peacock Creek. Dikes of diorite cut the greenstone, probably apophyses of the diorite mass on the north side of Kotsina River. The copper prospects of Peacock Creek are owned by the Alaska Kotsina Copper Company.

Rose claim.—The Rose claim of the Alaska Kotsina Copper Company is located on the point of the ridge between the two branches of Peacock Creek. It is a little more than 2,000 feet above the valley

[a] The use of the name Kotsina Mining Company has been abandoned by the owner of this property since this paper was written, but the name used in its place has not been learned.

of Kotsina River. The greenstone is cut by a perpendicular fault striking N. 25° E. This fault is easily traced for a distance of nearly 400 feet and is indicated by a zone of crushed greenstone with a maximum width of about 12 feet, in which the copper minerals are seen. Bornite, glance, chalcopyrite, and a small amount of native copper with malachite and a little red oxide as alteration products comprise the minerals associated with the fault.

White Dog and Mint claims.—Two claims on the west side of the more southerly fork of Peacock Creek have been partly prospected. The first of these, called the White Dog, is approximately 2,500 feet above Kotsina River. The country rock is greenstone and is cut by a fault plane striking N. 40° E. and dipping steeply westward. There is a crushed zone of rock along the fault ranging from $3\frac{1}{2}$ to $4\frac{1}{2}$ feet in width. The walls are well defined, and clay seams show where the principal movements have taken place. An open cut 25 feet long has been made in the crushed rock. Chalcopyrite or copper-bearing pyrite is scattered through the crushed rock and clay seams and has strongly colored them with iron oxide. Green copper carbonate occurs as a surface stain, but bornite and glance were not seen here. The fault is plainly marked along the steep mountain side for several hundred feet.

Two hundred feet above the White Dog, and a little to the north, is a claim called the Mint. A small fault with a strike of N. 15° W. and a dip of 60° W. cuts a grayish greenstone having amygdaloidal phases. The rock adjacent to the fault is broken and crushed, causing a zone with a thickness of 6 inches to 1 foot which, besides the greenstone, includes a little quartz and calcite accompanied by bornite and glance. Chalcopyrite was not observed, but a heavy stain of iron oxode seems to indicate that either this mineral or pyrite had formerly been present. There is a parallel fault 4 feet from this main fault, and both are cut perpendicularly by a third poorly defined fault having the same strike and carrying a little bornite. The main fault was traced for a distance of 500 feet.

Mountain claim.—The mountain claim is one of several on the north side of the east fork of Peacock Creek. It is about 2,600 feet above Kotsina River and consequently is at a greater elevation than the other claims described. In August almost no work had been done on it and only a few small stringers of copper sulphides were exposed.

SHOWER GULCH.

A small stream joining Kotsina River a short distance below the glacier in which its southern branch originates is called Shower Gulch from the waterfall near its lower end. Native copper is found near this fall in the amygdaloidal greenstone that forms the country

rock. Copper occurs as thin leaves or films in fractures of the greenstone and as grains and small slugs in the greenstone and in some of the amygdules. It is in places associated with secondary quartz, filling irregularly shaped veins or cavities. Several claims have been staked on Shower Gulch, but little prospecting has been done.

SURPRISE CREEK.

Surprise Creek is a northerly tributary of Kotsina River and heads in the high mountain southeast of the lower end of Kluvesna Glacier. Most of its bed is cut in the diorite mass previously referred to, and in a rude way follows the contact between the diorite and the greenstone on the east. It has a small eastern tributary, Sunshine Creek, which lies mostly in the greenstones. Tin is reported to have been found in the diorite of Surprise Creek, but the specimens of the supposed tin-bearing rock examined contained no tin, and no reliable assay tests of the rock are known to the writers. All the copper prospects are in the greenstone east of Surprise Creek. They are the property of the Alaska Kotsina Copper Company.

Laddie claim.—Between Surprise and Sunshine creeks is a steep gulch running down from the north. On the west side of this gulch and nearly 3,000 feet above Kotsina River is the Laddie claim. A very close-grained grayish "greenstone" forms the country rock and is cut by a fault striking N. 20° to 30° E. and dipping about 45° NW. Along the fault is a zone of crushed country rock ranging in width from 2 to 3 feet, in which is a quartz vein 18 inches thick. Besides quartz there is a small amount of calcite. The vein carries copper glance accompanied by a little bornite and chalcopyrite. In places the percentage of copper minerals in the vein is high, but they are not distributed uniformly through it. A line of prospect holes extends along the vein for a distance of 200 feet.

Sheehan claim.—At the Sheehan claim, 200 feet higher than the Laddie and a little farther east around the mountain side, the greenstone is cut by a fault striking N. 45° E. and dipping 45° NW. This fault resembles the Laddie fault in being accompanied by a zone of crushed rock, but the zone is here somewhat wider, ranging from 3 to 4 feet. A small quartz vein is exposed, in which the copper minerals are glance, bornite, and a little pyrite. The small veins of glance cutting the quartz are in places half an inch thick.

Hubbard claim.—About 300 feet east of the Sheehan claim and a little higher on the mountain the vein of the Hubbard is exposed in two open cuts. The vein is almost perpendicular and strikes N. 40° E. In the more southerly open cut there is a vein of white quartz ranging in thickness from 4 to 8 feet and carrying the copper minerals, chalcocite, bornite, and chalcopyrite, which are named in the order of their abundance. A strongly marked fault with 3 inches

of clay seam defines the north wall of the vein. Eight feet from the vein on the southeast is a second vein or lens of quartz 10 inches thick and also carrying chalcocite. Between the two veins is crushed greenstone. Nearly 200 feet to the northeast along the strike an open cut 40 feet long and 25 feet deep has been made across the vein. The fault is again seen along the north wall, but the single large quartz vein exposed in the other cut is here represented by many smaller veins of lenticular form up to 12 inches in thickness. Chalcocite and bornite are the copper minerals. Nearly 1,000 feet farther northeast a well-marked fault with a zone of sheared greenstone crosses the ridge between Kotsina River and the Hubbard claim and is said to extend as far as the glacier from which this branch of the Kotsina springs. There is little doubt that this fault is the continuation of that crossing the Hubbard claim.

KLUVESNA CREEK.

Kluvesna Creek and its tributary Fall Creek are the only streams besides Surprise Creek coming into Kotsina River from the north on which any prospecting or assessment work was done in the summer of 1907. Kluvesna Creek drains the main lobe of Kluvesna Glacier, and the smaller western fork known as Fall Creek originates in a minor lobe of the same ice mass coming down from the snow fields of Mount Wrangell. The valley floor is a broad gravel flat, and was once occupied by glacier ice, which has since retreated to its present position 7 miles from the river's mouth. The country rock is greenstone, except that the Chitistone limestone forms the top of the ridge west of the southern part of the river, and descends to the Kotsina River valley near its junction with the valley of Kluvesna Creek. Dikes of light-colored eruptive rock, mostly dioritic in character, cut the greenstones locally.

On the east side of Kluvesna Glacier and nearly three-fourths of a mile from its south end copper minerals have been found in the greenstone several hundred feet above the ice. Three open cuts show a light-colored rock—possibly altered greenstone—cut by irregularly branching quartz veins. The light-colored rock contains chalcocite and chalcopyrite scattered through it in specks rarely larger than a pin head. There are besides this small veins of chalcopyrite. The greenstone country rock locally contains small particles of chalcopyrite, a fact that may have some bearing on the origin of the richer copper sulphide ores.

West or a little southwest of the mouth of Fall Creek, and nearly 1,800 feet above it, is a short tunnel, which is the property of the Kotsina Mining Company.[a] This tunnel is on the north side of a

[a] The writers have lately learned that the name Kotsina Mining Company is no longer in use.

small gulch running down to Kluvesna Creek and is located at the contact of a fine-grained greenstone and a grayish amygdaloidal greenstone. The contact, which is parallel with several prominent fault planes cutting the country rock, strikes N. 35° to 45° W. and dips 50° SW. The fine-grained greenstone is much shattered and requires timbering to make it stand in the tunnel. Native copper appears as small particles in the amygdaloidal greenstone, both in the apparently unaltered rock and in portions that have been partly leached. It is also associated with small quartz and calcite veins in the greenstone. At many places where native copper is found there is a little red copper oxide. Several pieces of native copper and quartz weighing 20 or 30 pounds were piled on the dump, but nothing like them was seen in the tunnel or in the open cut above the tunnel.

On Fall Creek or its tributaries a number of small open cuts and short tunnels in which copper minerals were seen were examined. These small branches flow into Fall Creek from the west within the lower 2 miles of its course. Less than half a mile from the mouth of the most northerly branch there is a short tunnel on the south side of the stream driven along a north-south fault in amygdaloidal greenstone. The greenstone is crushed and contains small veins of quartz and calcite. A green stain of malachite appears on the surface, but within the crushed country rock both green and blue copper carbonates are found in a way that suggests them to be the alteration products of some earlier copper mineral deposited along the fault. Between the rock fragments along the fault there is in places a soft black carbonaceous filling with which the copper carbonates are mingled. Only a small amount of copper minerals is exposed by the tunnel.

South of this creek on the second tributary a short tunnel about 6 feet under cover was made along a perpendicular north-south fault plane in amygdaloidal greenstone. This tunnel is only a few feet above the creek and on its north side. The greenstone is cut by many small, light-colored, fine-grained, porphyritic dikes containing abundant grains or crystals of quartz. A very little bornite is associated with quartz veins in the greenstone.

Up the hill to the south and 375 feet above the short tunnel just mentioned is another tunnel 40 feet long, also in amygdaloidal greenstone. Here, too, the perpendicular north-south faulting is to be seen, and green copper stains appear on the surface of the fractured rock. The tunnel was driven to strike the supposed downward extension of an outcrop of greenstone, contaning native copper, exposed on the ledge 25 feet above the tunnel and about that distance to the south, but had not reached it. Bornite and copper carbonates in small amount were seen in a number of shallow open cuts a short distance southeast of this tunnel.

COPPER CREEK.

Copper Creek is the westernmost tributary of Kotsina River on which prospecting was done last summer. It drains a portion of the ridge between Kotsina River and Elliott Creek and joins the Kotsina 2 miles below Kluvesna Creek. All the geologic formations already named are present in the upper part of the basin—the Nikolai greenstone, Chitistone limestone, Triassic shales, and Kennicott formation. Their relations, however, are not simply those due to folding, for extensive faulting has accompanied the folding.

There are two principal branches of Copper Creek, but the western branch also forks at a point about 2½ miles from Kotsina River. Near this fork the limestone-greenstone contact crosses the two branches in a northwest-southeast direction, and good exposures of the limestone are found between the branches as well as on each side of them. The greenstone, however, is not exposed on the slope from the fork to the limestone outcrops between the branches.

The workings of the Mullen claim are between the branches, about 1,000 feet from the point where they separate and 275 feet above their junction. Three open cuts have been made along the foot of a limestone cliff. The strike of the limestone at this place is difficult to determine accurately, but is nearly north and south. It dips 45° W. In the northernmost open cut, which is 20 feet long and 10 feet in depth from front to back, a fault plane parallels the bedding and forms the west wall of the cut. The limestone is much broken, particularly near the fault, forming a zone of broken rock with a maximum width of 3 feet. In places the limestone is almost completely replaced by bornite and chalcopyrite. The best ore forms a poorly-defined vein, ranging in thickness from 12 to 18 inches, but does not outcrop on the surface. Azurite is more abundant than malachite where the copper minerals are oxidized, and in places the bornite is completely altered to azurite. Small calcite veins are numerous, especially in the brecciated rock near the fault, where the fragments have been cemented together with calcite. There are minor faults or joint planes in which a green copper stain is seen, but this appears to be derived from the main vein.

About 75 feet south is another open cut, where the fault planes are not prominent, but where the limestone is much jointed. Bornite occurs in isolated bunches in the limestone.

About 75 feet still farther south is a large open cut, and a shallow pit has been made. Several faults may be seen here, but the most prominent ones strike east and west and dip at a high angle to the south. The north-south faults are present, but are continuous for only short distances. Patches of crushed rotten rock stained with iron oxide and copper carbonate lie adjacent to the faults and joints. There are also small masses of high-grade bornite replacing the lime-

stone and forming bunch deposits in the country rock. These deposits were probably connected by the joints and faults with the channels carrying the mineral solutions, but this is not evident at the surface. A little chalcopyrite and both malachite and azurite are present with the bornite. Malachite is the surface stain, but below the surface azurite is the alteration product of the copper minerals. The bornite is cut by many thin veins of azurite, and in places contains small cavities lined with iron oxide or with azurite crystals. More work has been done in this place than in the first open cut, but less ore seems to have been taken out, if the amount piled near by is an indication.

ELLIOTT CREEK.

General description.—Elliott Creek (see fig. 2) is a tributary of Kotsina River, and joins it approximately 17 miles above the mouth of that stream, or 12.5 miles almost directly east of the Copper River crossing. It is reached by a trail which leaves the Kotsina trail at Willow Creek and crosses Kotsina River by a bridge about half a mile above the upper end of the canyon. This trail passes over the southwestern spur of Hubbard Peak and reaches an elevation of approximately 2,700 feet before the descent to Elliott Creek begins. A second trail used for the first time during the summer of 1907, leaves Elliott Creek about 6 miles above the mouth at Five Sheep Creek, and crossing the west end of the ridge south of the stream leads to the Nizina trail not far east of the new government bridge.

Elliott Creek is approximately 10 miles long, and throughout most of that distance flows in a direction about N. 30° W., but makes a sharp southerly bend before joining Kotsina River. More than 2 miles of the lower portion is through a narrow rock-walled canyon, but the upper part, along which the claims extend for a distance of $4\frac{1}{2}$ miles, lies in a narrow V-shaped valley. Between the upper cabin, situated about midway between the upper and lower ends of the claims, and the lower cabin, a distance of $2\frac{1}{8}$ miles, the creek descends 759 feet, or approximately 360 feet per mile. Above the upper cabin this gradient increases as the head of the stream is approached. Elliott Creek is fed in large measure by melting snow, and although the stream is not large, it is capable of furnishing considerable power with the head available.

The lowest and the only commercially important rock formation exposed in Elliott Creek valley is the Nikolai greenstone. All the copper prospects so far discovered here are associated with this rock. The massive bluish-gray Chitistone limestone is conformably overlain in some places by black and gray Triassic shales and thin-bedded limestones cut by light-gray porphyritic dikes and sills, and in other places is succeeded unconformably by coarse conglomerate of the Kennicott formation.

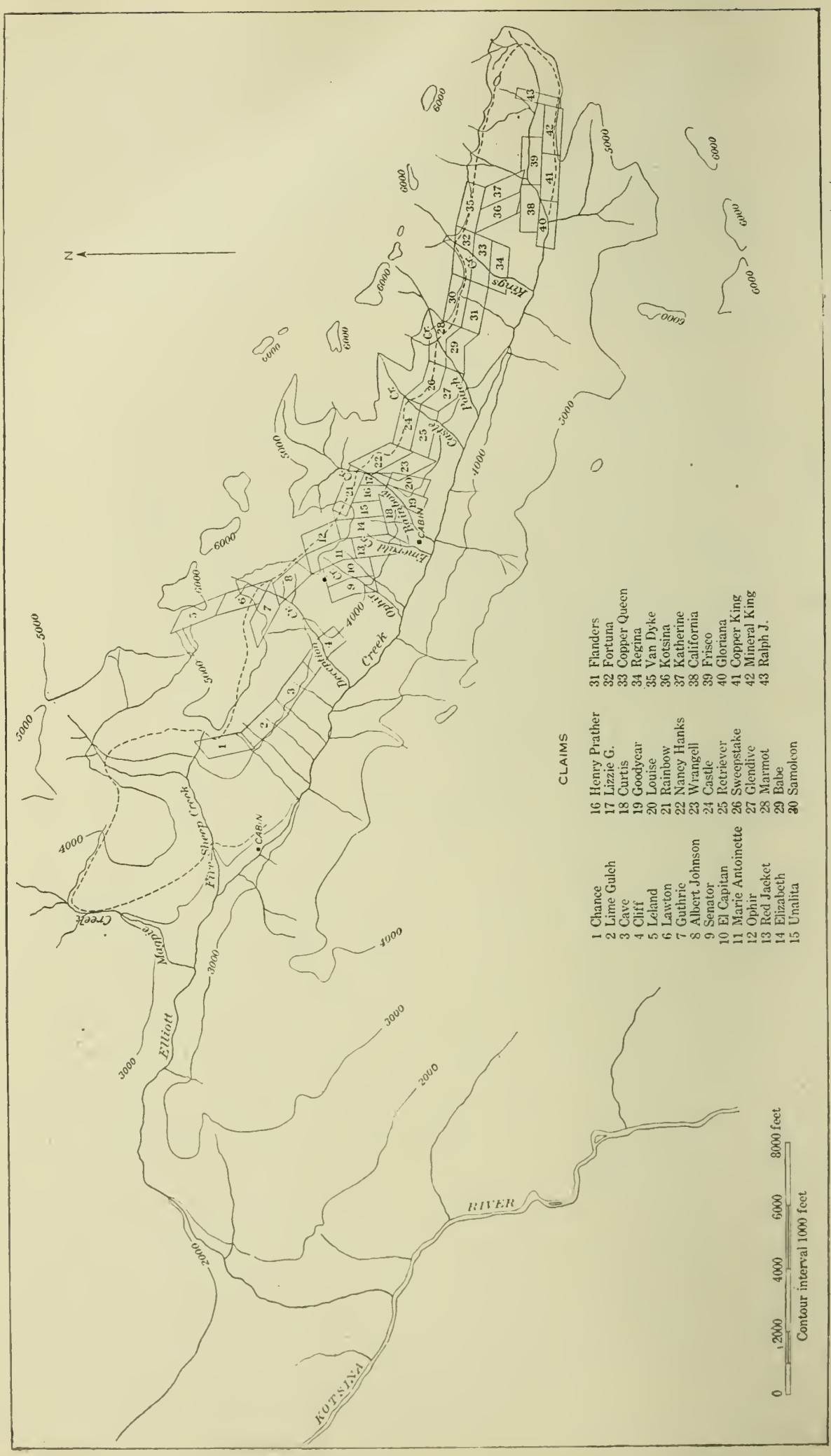


FIG. 2.—Sketch map of Elliott Creek and the copper claims. Dashed line indicates the limestone-greenstone contact.

In an ascent of Elliott Creek the greenstone and overlying limestone appear for the first time on Magpie Creek and continue eastward from that locality to the head of the valley. These two rock formations form a great anticline (fig. 3), whose axis is approximately parallel with the course of Elliott Creek. It pitches under the younger rocks at the eastern and western ends and dips into the ridges on each side of the creek (Pl. VII, *B*). North of Elliott Creek and at its upper end the Chitistone limestone forms a very prominent topographic feature. With the exception of the Copper King and Mineral King the claims described are on the north side of Elliott Creek and all but 8 are owned by the Hubbard Elliott Copper Mines Development Company. The description of the claims is given in the order of their location from east to west.

Copper King and Mineral King claims.—The Copper King and Mineral King claims, often spoken of as "the Kings," are the most easterly on Elliott Creek. They are located along the limestone-greenstone contact at an elevation of over 4,000 feet above the sea.

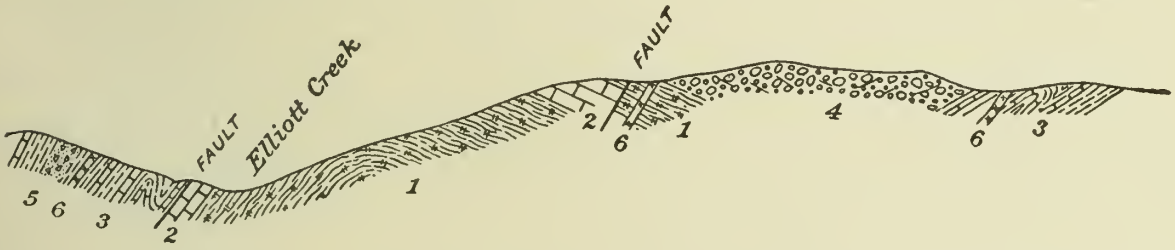


FIG. 3.—Cross section (somewhat diagrammatic) of the Elliott Creek anticline. 1, Nikolai greenstone; 2, Chitistone limestone; 3, contorted Triassic shales and limestones; 4, Kennicott formation; 5, tuffs and shales; 6, porphyritic dikes.

On the Copper King claim there is an open cut in the greenstone a little more than 100 feet below the base of the limestone cliff, 1,390 feet above the upper cabin. The copper minerals are found along a shear zone in the greenstone. Bornite is the principal copper ore, and is seen along fractures and between them replacing the country rock. Calcite veins are not so numerous as might be expected near the limestone contact. The shear zone, which, as far as can be determined at this exposure, runs parallel with the base of the limestone, striking N. 60° to 70° E. and dipping to the south, is mineralized for a thickness of about 10 feet, though the copper-bearing solutions have penetrated the country rock for a greater distance, as is shown by a slight alteration of the greenstone. There is some pyrite in the ore, and besides malachite a blue coating of copper sulphate appears in protected places. This open cut is reached by climbing over a steep rock slide.

The two open cuts on the Mineral King are reached by another hard climb over a steep snow-covered talus slope. These cuts are about 800 feet northeast of the cut in the Copper King. The lower one was filled with snow at the time they were visited, but the ore

piled up at one side consisted of bornite replacing greenstone. The second cut, 50 feet higher and about 100 feet farther west, is almost at the same elevation as the Copper King cut. The ore was found on the steep face of the cliff and consists of chalcocite, with a small amount of bornite replacing the greenstone along a fault or shear zone. Numerous close perpendicular joints running approximately N. 60° E. cut the greenstone, and there are a number of fault planes which strike N. 35° E. and dip 30° S. The trend of the disturbed zone is the same as that of the faults mentioned. The best ore has a thickness of about 6 feet and is traced for a distance of 25 to 30 feet along the strike, although the boundaries and extent of the ore body are somewhat indefinite. On the south, however, a fault plane makes a fairly well-defined wall. There is some rich ore at this exposure, but the development work is not yet sufficient to determine whether or not the ore body has any considerable extent.

Claim at the head of Queen Creek.—On the claim at the head of Queen Creek a small open cut has been made in the greenstone about 50 feet below the base of the limestone and shows small veins of calcite and a little quartz containing copper.

Van Dyke claim.—Two open cuts on the Van Dyke claim were visited, one 15 and the other 25 feet below the base of the limestone. The greenstone is stained with the oxidation products of iron and copper and contains also a small amount of pyrite, but the cut shows very little of the copper minerals.

Copper Queen claim.—The open cut on the Copper Queen claim is about 50 feet west of Kings Creek. It has an elevation of 905 feet above the upper cabin. The cut is nearly filled by the caving of the bank above, so that the face of the greenstone was not exposed. A large mass of the rock, however, which lay at one end was filled with a great number of tiny intersecting veins of iron and copper sulphide, either pyrite and chalcopyrite or, more probably, copper-bearing pyrite. The greenstone fragments were covered with the green copper coating.

Marmot claim.—A large open cut has been made on the Marmot claim at the base of the limestone between 200 and 300 feet west of Pouch Creek. The greenstone is much broken, and slicken-sided surfaces are numerous. The most prominent fault planes strike approximately N. 60° W. and are nearly perpendicular. Small calcite veins carrying a small amount of copper-bearing pyrite occur along some of the openings. A malachite coating was seen in the greenstone, but is not prominent along the main fault planes. Bornite was not observed.

Louise claim.—The Louise open cut is on the east side of Rainbow Creek and 50 feet above it, or 390 feet above the upper cabin. The country rock is greenstone and is cut by faults and joints. Slicken-

sided surfaces are common. The best developed fault planes strike about N. 20° W. and dip 45° to 50° W. Small calcite veins, having a thickness in general not greater than 2 inches and containing a little quartz, cross the country rock in all directions. Such veins are more numerous here than in most of the other workings examined. Bornite and chalcopyrite are the copper minerals present, and of the two bornite is the more abundant. They appear in the calcite veins and disseminated through the greenstone. The ore is best developed, however, in the calcite veins and the greenstone adjacent to these. It is difficult to give any definite statement of the thickness of the mineralized zone. The ore extends parallel with the creek for a distance of about 30 feet horizontally.

Above the cut on the steep hill slope green copper stains can be traced for a distance of 150 or perhaps 200 feet. Such an exposure as this may be the surface indication of an ore shoot, but the rich ore can not be traced for any considerable distance on the surface, usually not more than 25 feet and rarely as much as 50 feet.

Lizzie G. claim.—The open cut of the Lizzie G. claim is in the bed of Rainbow Creek only a short distance from the Louise. The greenstone at this place is sheared and plicated, but many of the resulting openings have been filled by infiltration of quartz and calcite. Quartz veins reach a thickness of 2 inches and carry considerable chalcopyrite. Calcite filling is, however, the more abundant, and in places the rock consists of about equal amounts of sheared greenstone and calcite similar to the knotty masses of schist and quartz seen in many regions where metamorphism has been greater than in this area. These calcite-greenstone veins, if such they may be called, carry a considerable amount of bornite and chalcopyrite and make a fine-appearing copper ore, but the open cut does not show how great a quantity may be present.

Goodyear and Henry Prather claims.—Directly opposite the Louise open cut, about 40 feet west of Rainbow Creek and 340 feet higher than the upper cabin, an open cut has been made in the claim known as the Goodyear. The amygdaloidal greenstone is cut by faults and is much jointed. The most prominent of these faults strike north and south and dip about 40° W. Another set of less well-developed faults has a more easterly strike and a lower dip to the northwest. Between two of the north-south faults is a mass of rock lighter in color than the greenstone outside the faults. This lighter rock is sheared or sheeted parallel with the faults and is filled with a great number of thin calcite veins containing chalcopyrite or copper-bearing pyrite and bornite, somewhat like the leaves of a book made of coarse paper. In the lower part of the cut this ore body is between 4 and 5 feet thick, and forms a lenticular mass about 20 feet long bounded by two north-south faults and a northeast fault. The

upper north-south fault is not continuous, but the lower foot-wall fault extends to the north for some distance. On the south this body of ore is much crushed and is filled with iron oxide. It can not be traced farther in that direction than the limit of the cut. Besides the thin veins of copper minerals in the sheeted rock there are small veins of calcite and ore throughout the mass.

Along the strike a short distance to the north, and a few feet higher, the light-colored, copper-bearing rock reappears, but the upper boundary of the mass is the fault which forms the lower boundary of the lower body. The ore body has a maximum thickness here of not less than 8 feet. An irregular branching calcite vein containing small horses of the light rock or main ore body reaches a thickness of 14 inches and contains chalcopyrite and bornite. This body of ore continues for a distance of 50 or 60 feet toward the north. These two bodies are portions of a single ore body included between two north-south faults and cut by later faulting. (See fig. 4.)

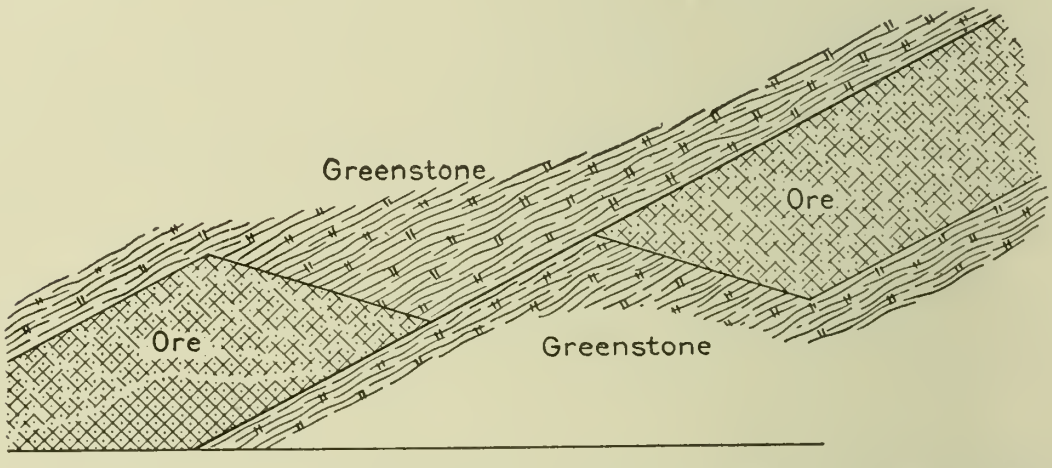


FIG. 4.—Diagram showing the faulted portions of the Goodyear claim, Elliott Creek.

Almost directly above the Goodyear on the hill slope to the west and not more than 100 feet away is the open cut of the Henry Prather. Here a north-south fault dips 60° W. and is intersected by two parallel faults striking N. 40° E. and dipping 30° to 35° W. These faults inclose a lenticular mass of rock 30 feet long and 5 feet wide (Pl. IX, *B*), whose weathered surface is lighter in color than the inclosing greenstone and which is similar in all respects to the ore body of the Goodyear. This lighter colored rock is impregnated in a similar manner with copper sulphides, and through it runs a vein of coarsely crystalline calcite carrying chalcopyrite and bornite, which are very rich in places. The calcite vein has an irregular thickness ranging from 8 to 12 inches, and in two places is offset by small faults to a distance of 10 inches.

The main north-south fault may be traced north for about 75 feet, and shows much green stain and some sulphides, but the large calcite vein and main ore body end, apparently having been faulted

off. Almost 50 feet from the ore body the large fault is intersected by a northeast fault. This also shows copper stain, and both contain small calcite veins with the sulphides.

Although no direct proof was obtained the similarity in character and appearance of these two ore bodies of the Goodyear and Henry Prather indicate that they are faulted portions of one mass.

Elizabeth claim.—The Elizabeth claim lies north of the upper cabin, and has received more attention in the way of development work than any other claim on the creek. This work consists of a tunnel and one or two open cuts. The tunnel is located in a narrow gulch a little more than 1,000 feet above the cabin. It has been driven into the greenstone in a northeasterly direction for 250 feet, and some ore has been uncovered, but it is not believed that the main ore body which outcrops on the hill above has been reached, and the work is to be continued. About 75 feet from the entrance the first copper appears in some lenticular veins of calcite and quartz, but there is only a small amount of this. In the face of the tunnel the greenstone is impregnated with bornite and chalcopyrite. Small veins of calcite also are present and carry the copper minerals. These small veins follow joint and slip planes in the greenstone and are rarely over half an inch thick. There is no well-defined master vein; the mineral waters appear to have followed a zone of fracture and faulting running, as closely as it is possible to determine at the tunnel face, in a nearly north-south direction. The greenstone has undergone considerable movement and slickensided surfaces are numerous. If the slip planes and joints follow any definite general direction, this direction could not be determined. At present the tunnel does not reveal the thickness of the ore-bearing zone, nor even its direction with certainty.

In the gulch directly above the tunnel to the north, and about 100 feet higher, is an open cut exposing the copper-bearing fault zone, which the tunnel is expected to cut. The greenstone is much shattered, and shows a number of fault planes the most prominent of which range in strike from N. 10° W. to N. 30° W. Movement along some of these planes has been very marked, and the rock is greatly crushed. Bornite and chalcopyrite are present in small calcite veins and also impregnating the greenstone in and adjacent to the fault zone. The green stain due to oxidation is prominent here, as it is in all places where the copper minerals occur, and makes it possible to trace the copper-bearing zone from the open cut in a direction N. 12° W. for several hundred feet up the hill, where several other small open cuts have been made.

Marie Antoinette claim.—Copper minerals are exposed in the Marie Antoinette claim in two open cuts on the top of a narrow ridge adjoining the Elizabeth claim on the northwest. These cuts

are within less than 100 feet of each other, and show shattered greenstone stained with the oxidation products of iron and copper. There are a number of faults which strike in different directions, and in the open cut on the west brow of the ridge a crushed vein of variable thickness, consisting of calcite and a small amount of quartz, is exposed. The greenstone also contains veinlets of calcite, which follow joint or slip planes and carry the copper and iron sulphides. The larger vein strikes approximately N. 30° W., a direction which would take it somewhat to the south of the other open cut. Near it a small perpendicular dike of fine-grained diorite from 2 to $2\frac{1}{2}$ feet thick cuts the greenstone.

Albert Johnson claim.—The Albert Johnson claim and the Guthrie claim described below adjoin each other end to end and lie parallel to and slightly below the greenstone-limestone contact. Deception Creek crosses their common end line at an angle of about 45°. Some open-cut work has been done, and a tunnel has been driven on the Albert Johnson about 100 feet east of Deception Creek. The tunnel is 30 feet under cover and is not over 150 feet below the base of the Chitistone limestone exposed to the north in the creek.

Small, nearly horizontal faults cut the greenstone, and the rock is otherwise broken by joints, giving it a blocky character. Calcite veins are present but not abundant. Copper ore is exposed in the tunnel and in the open cuts. When a piece of the copper-bearing greenstone is broken, bornite and chalcopyrite are found to be the copper minerals, the bornite predominating. The fault zone in which the copper sulphides occur can be traced by the green stain in a nearly horizontal plane almost around to the Guthrie tunnel, so that these two appear to form parts of one ore deposit.

Guthrie claim.—The tunnel of the Guthrie claim is on the hill slope west of Deception Creek, directly opposite the Albert Johnson tunnel and about 200 feet from it but 10 or 15 feet higher. Above the tunnel for a distance of 40 or 50 feet the surface of the country rock has been cleaned off, exposing small veins of calcite in shattered greenstone; these veins carry the sulphides bornite and chalcopyrite. The freshly broken greenstone adjacent to these small veins is also seen to be impregnated with the sulphides. There is no well-defined vein, but the jointing or faulting has permitted the mineral-bearing waters to circulate through a shattered zone in the greenstone. The tunnel is not more than 100 feet below the base of the heavy limestone as it is exposed in the creek to the north, which would account for the considerable amount of calcite present in the greenstone.

Leland and Lawton claims.—The Leland and Lawton claims are located in the saddle between the heads of Five Sheep and Deception creeks, which here has an elevation of more than 2,500 feet above the lower cabin. They lie north of the main body of the Chitistone

limestone, whose scarp forms the prominent cliff on the southern brow of the spur to the south. This unusual location apparently above the limestone is due to faulting, which brings the greenstone up against the Kennicott conglomerate or rather against the large porphyritic dike which here separates these two formations. On the Lawton claim a fault which strikes N. 30° W. and dips 50° to 60° S. is seen between the greenstone on the south and the porphyry dike on the north. The dike here shows a thickness of 30 to 35 feet. Several open cuts have been made in the greenstone and show small amounts of pyrite and chalcopyrite impregnating the rock adjacent to joint or fault planes. Green copper stain and also copper sulphate were seen in a number of other places. The copper minerals where observed were all within a few feet of the porphyry dike, but any other relation between the two was not evident.

Cliff claim.—The Cliff claim is on the west side of Deception Creek. Two open cuts have been made at an elevation of 600 feet above the mouth of this stream. The greenstone is cut by numerous fault planes, and slickensided surfaces are frequently seen, but perhaps the most prominent of the planes of movement strike nearly east and west and dip about 45° N. The green copper carbonate and the oxide of iron stain the greenstone. Small amounts of the copper sulphides also are exposed along joint planes, but no considerable exposure of ore has been made.

Chance claim.—The Chance is the most westerly of the patented claims and includes the prominent point of the limestone cliff which is seen on entering the valley. A small open cut only a few feet below the base of the limestone shows the green copper stain and a little bornite in the greenstone.

KUSKULANA RIVER BASIN.

GENERAL DESCRIPTION.

Kuskulana River receives its greatest supply of water from Kuskulana Glacier, an ice stream made up by the union of four principal branches coming down from the southwest side of Mount Blackburn. The river is a little over 21 miles long, and in the upper half passes through a broad gravel-floored glacial valley between high, rugged mountains. After leaving the mountains it flows for more than 10 miles, most of the way in a narrow rock-walled canyon, across the broad valley of Chitina River and joins that stream 10 miles above Copper River. Strelna Creek is the largest tributary of Kuskulana River. It rises in the mountains about the head of Elliott Creek and joins the Kuskulana 3 miles from Chitina River, thus having a length of 12 miles.

Most of the copper prospects are in the vicinity of Kuskulana Glacier, where the Nikolai greenstone and Chitistone limestone are

well exposed. There are, besides these two formations, some rocks of doubtful identity in the vicinity of Nugget Creek, a western tributary joining Kuskulana River just below the glacier. These rocks are probably the same as some at the head of Kotsina River which have been included in the Nikolai greenstone, but may be older. Triassic shales and limestones are well developed east of the Kuskulana and are also represented in a small area west of it.

The best-known copper properties of this area are on Nugget Creek, but there are other prospects on one or two neighboring streams tributary to the main river on the west side and in the vicinity of the glacier on the east side, as well as on Slatka and Trail creeks. There are also a few prospects on the head of Strelna Creek.

NUGGET CREEK.

General outline.—Nugget Creek drains the southeast side of the mountain mass whose northwest side is drained by Peacock, Roaring, and Rock creeks of the Kotsina basin. Several of its branches are fed by small glaciers. The stream is about 6 miles long and joins Kuskulana River less than a mile below the glacier.

The country rock includes amygdaloidal greenstones and other greenish rocks, which differ somewhat in appearance from typical exposures of the Nikolai greenstone and might be separated from it on closer study. A small area of Chitistone limestone outcrops on the mountain slope east of the upper part of Nugget Creek, and near it, along the creek bed, is a small exposure of gabbro.

Most of the copper prospects, of which there are a considerable number, are situated in the lower or southern part of Nugget Creek valley. Collectively they constitute the Alaska Consolidated Copper Company's properties, only a part of which were examined by the writers. The claims on which most work has been done are located on the small rounded hill between the lower end of Nugget Creek and Kuskulana Glacier. It was not possible in the short time available to visit any other properties than those on this hill, so that no description of claims in the Nugget Creek valley north of the hill or west of the stream can be given. A good trail leads from the creek's mouth to the camp, where several very comfortable cabins have been built.

Valdez claim.—On the south slope of the rounded hill referred to above is a claim called the Valdez. It is crossed by a fault or a set of parallel vertical faults, running N. 65° E., along which the ore is deposited. The continuation of the fault or faults for a distance of several hundred feet is shown by a line of test pits, but how much farther they extend was not learned. A tunnel run in toward the north and 30 feet under cover gives a cross section of the deposit. At the mouth of the tunnel is greenstone separated by a fault from a large calcite vein on the north. The calcite vein has a width of 24 feet, as meas-

ured along the tunnel wall. This wall, however, is not exactly perpendicular to the course of the faults. After passing through the calcite vein the tunnel penetrates a close-grained, dark-gray rock, possibly one phase of the greenstone series, for a distance of 5 feet. This latter rock and the vein are separated by a fault, along which is a seam of blue and yellow clay, ranging from 2 to 3 inches in thickness and containing small crystals of chalcopyrite. All of the calcite vein as exposed in the tunnel is ore. Bornite is the principal copper mineral, and is accompanied by chalcopyrite in minor amount. Movement has taken place along both faults since the ore was deposited, and the country rock, as well as the vein matter, is jointed and crushed. The greenstone is sheeted parallel to the fault, but the harder, close-grained rock in the face of the tunnel was more resistant and broke in angular blocks. The calcite vein is also much broken and in places granulated.

A prospect hole or crosscut a short distance northeast of the tunnel did not expose the vein, but 300 feet still farther to the northeast an open cut shows greenstone faulted against a light-colored rock, consisting chiefly of calcite and quartz, much shattered and impregnated with bornite and chalcopyrite.

Thirty feet to the southwest along the vein from the tunnel mouth is a shaft which in August, 1907, was partly filled with water, but was said to be 30 feet deep. The shaft is sunk in the vein matter, but here the vein has a thickness of only 8 or 9 feet. On the north side is greenstone, much sheared, and containing thin calcite veins accompanied by bornite. It is not evident from the exposures why the position of the greenstone with reference to the calcite vein is here reversed. The ore is similar to that in the tunnel. No traces of the vein or fault were seen on the grassy hill slope southwest of the shaft, nor were they expected, since no test pits had been dug and the country rock was not exposed.

One Girl claim.—The One Girl claim is on the west slope of the hill between Nugget Creek and the lower end of Kuskulana Glacier. A tunnel called the "mud tunnel" has been driven on the south side of a small gulch and extends into the hill for 100 feet in a direction S. 75° W. Of this tunnel 91 feet is in frozen slide rock, and is reported to have caved in sometime during the early fall. The remaining 9 feet of the tunnel is in amygdaloidal greenstone, the cavity fillings being calcite. No ore was observed in the face, but the tunnel had not been extended far enough to encounter the mineralized body of rock seen on the hill nearly 300 feet higher than the tunnel, toward the southeast. This "lead" is amygdaloidal greenstone country rock impregnated with fine particles or grains of chalcocite in association with small calcite veins and epidote. Several open cuts extending along a line from southwest to northeast show the same copper-bear-

ing greenstone, but no work has been done to indicate the width of the zone, or any of its other dimensions. This ore, if the copper content is sufficient to warrant the use of the term under the conditions prevailing in Alaska, is similar in many respects to that of the Copper Queen claim north of the Nugget Creek camp.

Nugget Creek received its name from the large mass of native copper found in the creek bed a short distance above the camp. This nugget is estimated to weigh between 2 and 3 tons, and is too heavy to be removed economically by any means of transportation now available. It is 7 feet in its greatest dimension, 3 feet 2 inches wide in the middle, and has a maximum thickness of 12 inches, but the average thickness is probably less than 6 inches. Many smaller nuggets, ranging in size from shot to pieces of several ounces or pounds, are found in the gravels of the creek, but their bed-rock source has never been discovered.

STRELNA CREEK.

The copper prospects of Strelna Creek are of interest chiefly as showing a close relation between copper deposition and the limestone-greenstone contact. The Chitistone limestone forms numerous cliffs in the upper part of the creek, particularly on the branch leading to the Elliott Creek pass.

About a mile southeast of the Elliott Creek pass a small area of Chitistone limestone caps the greenstone of the ridge south of Strelna Creek. The north contact of the two formations is here a fault contact. From 6 to 8 feet of the decomposed greenstone along the fault is heavily mineralized with pyrite, weathering to brown iron oxide. Along with the pyrite is a little copper, as is shown by the green stain of malachite. In the heavy overlying limestone, but not over 10 to 20 feet above the contact, thin veins of copper-bearing pyrite were seen in the limestone. Stringers and small bunches of ore are not uncommon in the underlying greenstone at various places on the creek.

LAKINA RIVER.

Lakina River rises in an area of glacial drainage of minor importance lying between the much more extensive basins of the Kuskulana Glacier on the west and the Kennicott Glacier on the east. The Lakina is not as large or as turbulent a glacial stream as the Kuskulana or the Kennicott.

The trail regularly traveled through this region reaches Lakina River about 6 or 7 miles below the lower ends of the two glaciers from which the river emerges. This portion of the valley of the Lakina differs somewhat from the valleys of Kuskulana and Kennicott rivers where they flow from their glacial sources in that it has a more basin-like expansion in its lower half. This basin-like expanse, which is about 2 miles wide along the trail and gradually narrows

into a mountain gorge valley one-half mile wide toward the head of the river as the glaciers are approached, is floored with deposits of gravel, sand, and mud.

In an ascent of Lakina River from the main trail, the first bed rock to present itself along the margins of the flat gravel floor of the valley is the Nikolai greenstone. This rock appears on both sides of the valley where the valley begins to become more restricted, about 3 miles below the glaciers, and rises in steep mountain slopes on both sides. Above the greenstone the Chitistone limestone presents its characteristic cliff-like faces, and above the Chitistone limestone a series of shales and thin-bedded limestones on the east side of the valley forms bare slopes that are also present, though not so evident, on the heights west of the river.

The camps of two prospecting parties are located within a few hundred yards of each other on the west side of the Lakina about a mile below the glaciers from which the river flows. The copper prospects occur at comparatively low elevations above the river in the greenstones that form the steep western side of the valley at this place.

The prospect farthest up the river is about 250 feet up the mountain side from the upper cabin. A short open cut, about 6 feet deep, has been made on a shear or minor fault plane that strikes N. 30° W. and dips 70° SW. into the country rock of amygdaloidal greenstone, which at this place is weathered to a reddish-brown color. The walls of this plane are separated at this opening for about 2 feet, and the space thus formed contains a filling of crushed and slickensided slabs and fragmental pieces of the country rock, the whole being cemented together by the deposition of quartz in the interstices. The quartz in one place is somewhat continuous along one of the walls for a few feet and has a thickness of from 1 to 2 inches. Most of the filling, however, is crushed country rock. A small amount of native copper in the form of specks and scales occurs within this filling. The amygdaloidal greenstone country rock just north of this filled space is checked with thin veinlets of quartz and contains some scattered chalcopyrite in specks and films. The narrowness of the opening makes it impossible to give any idea of the extent or amount of mineralization at this place.

The second prospect of this vicinity is similarly located on the lower slopes of the mountain side only a few hundred yards south of the one just described. At this locality the natural exposure of the rocks is good enough to exhibit the so-called pseudobedding that the Nikolai greenstone shows in many localities. Here this bedlike structure of the greenstones strikes N. 70° E. and dips 45° SE. Apparently there has been some shearing or movement along a major plane of pseudobedding or faulting as well as movements along joint

or other pseudobedding planes parallel to the principal one. This is shown by clean block or slab spalling for a distance of 500 to 600 feet on the strike and dip above recorded. This well-exposed face extends up the mountain side to the west and above the camp in a diagonal direction. The surface of the exposure is a natural dip slope along the major pseudobedding plane, offset somewhat by parallel bedding or joint planes. Slickensided surfaces may be observed along the joints or planes, and a tendency toward plication, indicative of shearing movements, is present. A small stream flows down over the surface of this rock incline. Along the major pseudobedding plane at this locality there is a somewhat continuous sheet-like filling of rock that does not look very different from some phases of the country rock at this locality and elsewhere. This sheet-like filling ranges from 1 to 6 or 8 inches in thickness and, as the surface of the rock incline is now exposed, this material lies in patches as a veneer over the surface of the country rock. It does not appear to be so markedly siliceous as the filling in the prospect several hundred yards to the north. It is this filling that contains the native copper in specks, flakes, slugs, and nugget-like lumps. No pieces of native copper of large size were observed, the largest pieces seen being about 2 inches by one-half inch in area; the size of these, as they are exposed on the surface, is due to the flattening and spreading to which they have been subjected by the impact of material carried down over this steeply inclined rock surface by the stream. The surface exposure of this sheet of native copper-bearing material, which lies bare over an area of about 400 by 20 to 30 feet, has been well picked over for specimens, and most of the larger pieces of copper originally present have been removed. For this reason it is impossible to give an estimate of the quantity of native copper that a given volume of the sheet-like filling along this shear plane may have originally contained. No work has been done in opening up the locality to show how extensive or persistent the deposit may be in any direction, and there appears to be no evidence to justify an assumption that there is a mass of native copper-bearing rock 20 to 40 feet wide extending into the mountain in a direction perpendicular to the strike of the pseudobedding.

High up on the mountain side, 2,400 feet above and three-fourths of a mile west of the camps on the river, some surface stripping has been done that exposes a fault in shattered amygdaloidal greenstones. This fault strikes N. 15° E. and dips 75° W. The walls are 18 inches apart and the space is occupied by what appears to be a gouge of crushed country rock, the 6 inches of material adjacent to the hanging wall being essentially earthy and the remaining 12 inches on the foot wall being cemented by a quartz filling. Apparently just enough copper-bearing mineral matter is associated with this cemented

gouge to stain the surface of the 18 inches exposed with green carbonate films. No other copper minerals seemed to be present, but some may be finely disseminated through the cementing material. A very little bornite in specks and stringers not over one-eighth inch thick was observed in a piece of loose material at this place.

KENNICOTT RIVER BASIN.

The summer trail that leads through the mountains east of Lakina River to the Kennicott Glacier follows the banks of the Lakina to Fohlin Creek, a tributary flowing from the north. The trail then ascends Fohlin Creek about 2 miles to its first large tributary from the east, locally known as Bear Creek, and continues up the valley of Bear Creek to Kennicott or Fourth of July Pass. From this mountain gap the trail descends Fourth of July Creek to the western margin of the Kennicott Glacier, down along which it continues to Kennicott River.

HIDDEN CREEK.

Hidden Creek is a tributary to Kennicott Glacier on its west side, about 4 miles northeast of the mouth of Fourth of July Creek. It presents a feature of lateral valley drainage that is unique in a way, yet also characteristic of many glacial valleys that are tributary to larger glacial valleys where the main ice stream still flows past and completely dams the mouth of the smaller valley. Considered by itself, the valley of Hidden Creek presents all the features of larger glacial valleys. The head of the valley comprises ample cirque basins for the accumulation of snow and its transformation into the ice of comparatively small glaciers that now exist at its head. These glaciers flow from their basins and terminate well down toward the valley level, but they do not extend into its flatter main portion. From them issue small streams that within a short distance join to form a creek of good size that flows down over the gravel-floored part of the valley. At its lower end the valley of Hidden Creek is completely dammed by the Kennicott Glacier, which ponds back the waters of the stream so as to form a lake which occupies the entire lower valley. This body of water is known as Icy Lake. It is one-half mile across and extends 1½ miles up the valley to a point where the gradually ascending gravel floor rises above its surface. This gravel floor continues as bare flats to the foot of the slopes of the cirque basins, from which the small steep glaciers occupying the head of the valley descend. The stream flowing over it from the glaciers at its head to the lake at its foot is about 2 miles long and has been well named Hidden Creek, as its existence is not to be suspected and it can not be seen until the valley is actually entered. About half a mile above Icy Lake on the

south side of the valley a small stream that heads near Fourth of July Pass flows out of a steep mountain gorge. This stream is locally known as Glacier Creek.

The steep walls of both the north and south sides of the valley of Hidden Creek expose on the lower halves of their slopes the Nikolai greenstone, above which rise practically inaccessible cliffs of the massive Chitistone limestone. A number of lode claims have been located along the contact of the greenstone and overlying limestone, where in places a little evidence of copper mineralization is to be seen. Most of these locations were made in 1906, and during the summer of 1907 assessment work was performed on them with a view to prospecting the ground.

The Great Northern Development Company had in this neighborhood for part of the season a crew of men who expended most of their labor in making a trail to the valley by following along the steep mountain that bounds the western side of the Kennicott Glacier for a couple of miles south of Hidden Creek. This trail was not completed.

The only actual work on claims located in the Hidden Creek valley was done by the Valdez Exploration Company. This company packed its supplies with horses up a trail over the western lateral moraine of Kennicott Glacier to the Hidden Creek valley, thence by a hazardous route across the ice that dams that valley to the north side, and thence up the northern shore of Icy Lake to its head. The camp was located 500 feet above the bed of Hidden Creek on a small area of bench ground, about 4,100 feet above sea level, that lies in the fork formed by the junction of Hidden and Glacier creeks. During the summer season of 1907 five or six men were employed by the company in prospecting a group of 25 lode claims, more or less, some of which are located on the greenstone-limestone contact that extends along the south side of the Hidden Creek valley above Glacier Creek. About half a dozen claims extend from this group along the contact to the west and across the course of Glacier Creek into an area of greenstones. Another chain of claims has been located up the valley of Glacier Creek and across the divide at its head into the headwater drainage area of Fourth of July Creek.

Most of the work on Hidden Creek is on its south side, about a mile above the camp, and consists of open cuts in the greenstones about 300 to 400 feet below their contact with the overlying limestones. All the work done during 1907 was necessarily in the form of open cuts, because of the difficulty of getting supplies into the place, especially timber for tunnel work, necessitated by the condition of the rock. No timber of any kind grows near Hidden Creek. Five open cuts were seen on claim 3 at this locality, at an elevation of from 4,800 to 4,900 feet above sea level, in much-sheared greenstones, the

shattered blocks and fragments of which are tightly keyed into one another. The displacements that the greenstones have undergone at this place have been severe enough to obscure the pseudobedded structure to a large extent. The mineralization through and between these keyed shattered blocks consists of irregular and disconnected stringers of bornite with lumps of the same mineral, some of which may weigh as much as 20 to 30 pounds. There is no continuity to the mineral deposits. They appear to be scattered erratically through the greenstones in an irregular zone for a width of 25 to 75 feet, and by far the greatest amount of this material is only shattered country rock.

GLACIER AND FOURTH OF JULY CREEKS.

Nebraska claim.—About three-fourths mile up Glacier Creek, at an elevation of approximately 4,800 feet above sea level, an open pit 8 feet square and 8 feet deep has been sunk, on what is called the Nebraska claim, in a shattered mass of the greenstone that forms a low knoll in the valley. This knoll appears to be a slide mass from the mountain side on the east. Green copper carbonate stains, specks of bornite, and one speck of chalcopyrite were observed in some of the pieces of rock that came from this pit, but nothing more was revealed. There is said to be a surface showing of chalcocite, upon which no work has been done, in the greenstones about 400 feet below the limestones on the southeast side of Glacier Creek opposite the camp.

Bekka and Eli claims.—Above the Nebraska claim the Chitistone limestone dips southward under thin-bedded limestones and shales. But the stratigraphic continuity of the rocks that occupy the headwater areas of Glacier and Fourth of July creeks is disturbed by a line of major faulting that passes in an east-west direction through the head of Fourth of July Creek. This fault throws the heavy-bedded Chitistone limestone to the surface again on the divide between Glacier and Fourth of July creeks, where it is exposed for a thickness of about 600 feet. There is probably a minor fault that passes across Glacier Creek north of and parallel to the major displacement on Fourth of July Creek. Over this faulted area the Bekka and Eli claims extend, crossing the divide to the head of Fourth of July Creek, where the major fault brings the thin-bedded limestones and shales against the greenstones. In the greenstones at the head of the creek, about 200 feet below the massive Chitistone limestone, is a bed of crystalline rock about 30 feet thick that has the attitude of a sill. Above the sill-like rock at this place is typical amygdaloidal greenstone that does not appear to be altered from its usual texture in any way. Along the contact between this crystalline rock and the overlying amygdaloidal greenstone are a few thin seams

of chalcopyrite, and there are also specks of this mineral within the amygdaloid a few inches from the contact. Bornite occurs associated with this chalcopyrite in very small quantities, and the presence of a small amount of chalcocite is suspected from its occurrence in a piece of rock not in place picked up below.

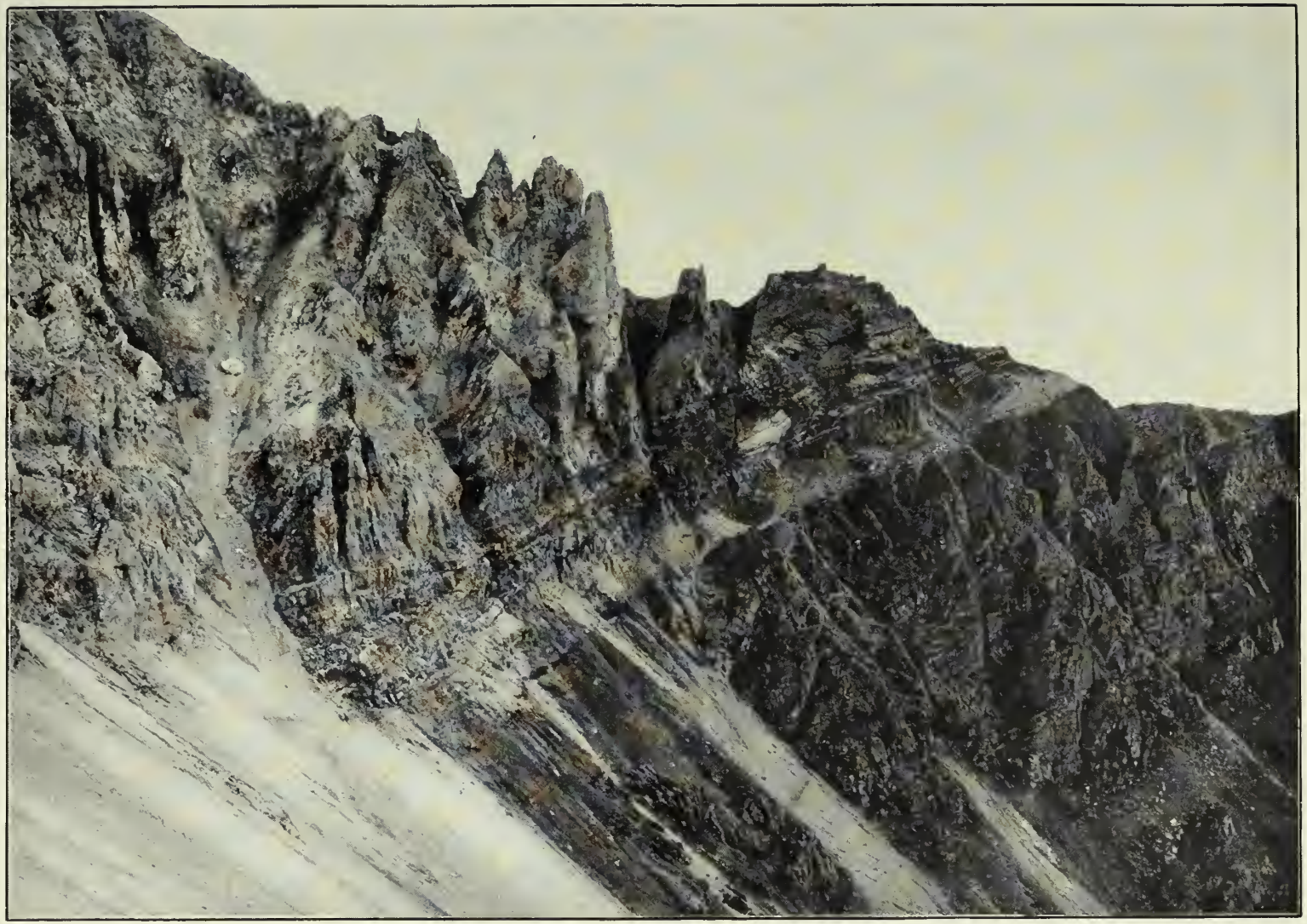
BONANZA CREEK.

The Bonanza mine, on the most valuable known copper deposit of Chitina Valley, is situated at the head of Bonanza Creek, about 1½ miles east of Kennicott Glacier and 7 miles north of the glacier's southern extremity. It is the property of the Kennicott Mines Company, and is the only property visited during the season that gives promise of shipping ore in a commercial way in the near future. Two other groups of claims, known as the Jumbo and Independence groups, are situated in the vicinity and are owned by the same company.

Bonanza Creek is about 3 miles long and heads on the west side of the high mountain ridge running north and south between Kennicott Glacier and McCarthy Creek (Pl. VIII). Its general course is southwest. The company's main camp and office, however, are located at the mouth of National Creek, almost 4 miles by trail from the mine. A new trail, sufficiently wide for a wagon road, is nearly completed and leads from the lower camp to the upper one, and a second trail of easy grade and good width leads down the east side of the glacier to the Kennicott River crossing.

South of National Creek the high north-south ridge between the glacier and McCarthy Creek is made up of Triassic shales and limestones, intruded by large masses of a light-gray quartz porphyry. These Triassic rocks and the intrusive are separated by a great fault from the greenstone and overlying Chitistone limestone on the north. The strike of the limestone is northwest and southeast, and its dip averages between 25° and 35° NE. It therefore cuts diagonally across the main ridge and appears at the glacier's eastern edge, nearly 9 miles north of the head of Kennicott River. The limestone here has a thickness of more than 1,000 feet. Still farther northeast the Triassic shales conformably overlying the heavy limestone reappear, but they do not occur within the area of the copper-bearing rocks. Bonanza Creek and the other creeks where copper claims have been located lie wholly within the greenstone-limestone area.

The Bonanza mine (fig. 5) is situated on the west side of Bonanza Creek, on a spur running down to the southwest from the main ridge. This spur divides Bonanza Creek from a small southwestward-flowing tributary heading just west of the mine, and is crossed by the greenstone-limestone boundary about one-half mile southwest of the main ridge. On the axis of the ridge this boundary has an elevation



BONANZA MINE, FROM HORSESHOE TRAIL.

of approximately 6,000 feet above sea level, or 3,800 feet above the mouth of National Creek, where the ore bins are to be built. To the southwest the spur is greenstone; to the northeast it is limestone, ris-

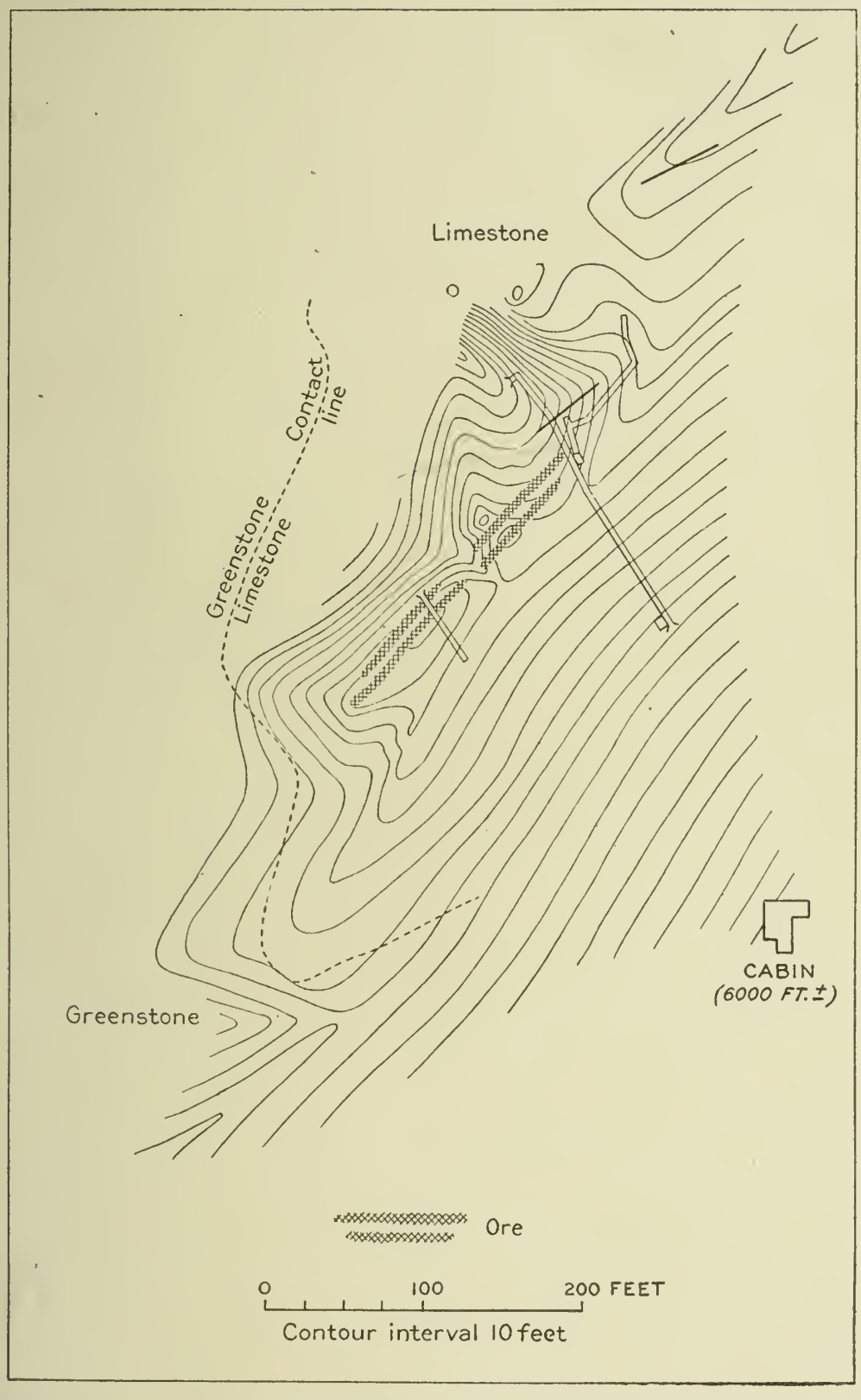


FIG. 5.—Sketch map of the Bonanza mine, showing the limestone-greenstone contact, the location of the rich ores of the surface, and the tunnels.

ing to an elevation more than 1,000 feet greater than that of the contact.

The greenstone immediately below the ore body is variable in texture and general appearance. Part of it is amygdaloidal, but

porphyritic intrusive phases are also present. Amygdules are not confined to the upper part of a flow, but are present throughout from bottom to top. In some places they have been dissolved out on exposed surfaces, leaving a cellular rock that looks like a recent lava. Between the greenstone and overlying limestone there is a bed of green and red shale having a thickness of about 5 feet. This shale forms a narrow bench for a short distance along the northwest side of the ridge, but is everywhere covered with talus and is only found after a careful search. The base of the limestone consists of not less than 40 feet of coarse gray, slightly argillaceous rock, whose broken surface in places is covered with flattened cylindrical bodies that immediately suggest organic material of some kind, but a careful examination of the markings did not indicate such origin, and it is probable that they merely represent some peculiarity of fracture. Over this is a few feet of impure shaly limestone, which in turn is overlain by dark and light-gray massive beds which carry the ore bodies. At the mine the limestone dip is slightly variable, but averages about 22° toward the northeast.

The limestone is broken by numerous faults and fracture planes, the most prominent of which are nearly perpendicular and range in strike from N. 40° E. to N. 70° E. A minor set of fault planes, with about the same strike, dips steeply to the west. Another set runs in a northwesterly direction, and in several places striations on slickensided surfaces or clay seams show that the movement was horizontal.

Fault planes with low dips, some of them nearly horizontal, are also present. None of the faults observed give evidence of much displacement, but together with the numerous joints they afforded an opportunity for mineral-bearing waters to enter the limestone. The principal fault planes—those running from northeast to southwest—form what may be described as a sheeted zone in the limestone. This zone has a width of 50 or 60 feet and extends through the shale bed into the greenstone below, but is less noticeable in the greenstone than in the limestone. A vertical displacement of 2 feet occurred in the limestone-greenstone contact along one of the fault planes in the shear zone and is the maximum displacement observed. This zone of fracture and slight displacement was not traced in a well-developed form for any considerable distance to the northeast, although the limestone exposures are on the whole very good, and one would expect to find it with little difficulty.[a]

The copper ores are chalcocite and azurite. The chalcocite is in veins or tabular masses of solid ore up to 5 or 6 feet in thickness, in large irregularly shaped bodies, and in stockworks in the brecciated limestone. Two principal veins of chalcocite are seen on the

[a] Since visiting this region the writers have been informed that the shear zone crosses to the McCarthy Creek side of the ridge northeast of the Bonanza mine.

surface. They stand almost perpendicularly, 12 to 15 feet apart, and strike N. 41° E., forming the comb of the sharp ridge, but crossing it at a slight angle, as the ridge at this place has a more nearly north-south direction than the veins. The veins do not extend down into the impure lower part of the limestone, but end abruptly and flatten out on reaching it. In places the precipitous northwest face of the ridge is plastered over with masses of solid chalcocite for a distance of 50 or 60 feet vertically below the top.

Azurite appears on the surface of the chalcocite and also as a lining of small vugs in the glance, but it is present chiefly as thin veins that form a network in the limestone and probably are due to the alteration of original chalcocite veins, for some of the azurite has an inner core of chalcocite. Azurite is more conspicuous than chalcocite in the northern 150 feet of the ore body, but chalcocite forms the great mass of the remainder. The ore bodies formed along the northeast-southwest faults of the northern part of the deposit are not the direct continuation of the large chalcocite veins at the south, but lie in nearly parallel veins which cut the ridge at a greater angle, their strike being about N. 60° to 70° E. The very rich ore can be traced on the surface for a distance of about 250 feet. It ends abruptly on the south in a nearly vertical limestone wall, but on the north gives place to the lower grade ores, consisting of small veins of azurite and chalcocite with scattered masses of chalcocite, some of them weighing several tons. This lower-grade ore shows on the surface for a distance of at least 150 feet northeast from the high-grade ores, and small scattered azurite veins extend still farther in that direction. The ore, as it shows on the surface, therefore, extends northeast and southwest along the strike for a distance of 400 feet. The thickness, however, is more indefinite, but the very rich ore, with its included limestone, as seen at the surface, has a width of approximately 25 feet, although the thickness of ore sufficiently rich to be mined may be greater.

A little chalcocite and less bornite is found in some of the shearing planes in the greenstone, but it does not extend far into the greenstone. The quantity is small and inconspicuous and might readily pass unobserved. A small amount of epidote is associated with it in places. The main shear zone in the greenstone cuts an older set of quartz-epidote veins, whose direction is about north-northwest. These quartz-epidote veins do not intersect the limestone. They reach a maximum thickness of 1 foot and carry small amounts of chalcocite, bornite, and native copper.

Two crosscuts (fig. 5) have been driven in the ore body in a direction N. 33° W. They are, therefore, not exactly perpendicular to it. The longer of these crosscuts starts on the east side of the ridge and 75 feet below its top. It is 180 feet in length and extends through

to the west side of the ridge. The richest ore, consisting of large masses of chalcocite with some included limestone, is encountered at a distance of 90 feet from the tunnel's mouth and continues for a distance of 21½ feet, as measured in the roof. There are smaller bodies of chalcocite, however, for a distance of 10 or 15 feet on either side of the main ore body. About 115 feet from the entrance to the tunnel a winze 33 feet deep was sunk in the ore, and from the bottom a drift zigzags northward approximately 110 feet.

About 120 feet southwest of this tunnel is a parallel tunnel driven from the west side of the ridge and 50 feet lower than the little saddle above it on the north. This tunnel starts in a face of solid chalcocite and extends S. 33° E. for 50 feet. The ore, which is chalcocite with a small amount of azurite, is exposed for 34 feet along the tunnel, but is interrupted by horses of limestone. The remainder of the tunnel shows limestone cut by small azurite veins and in places containing a small amount of chalcocite.

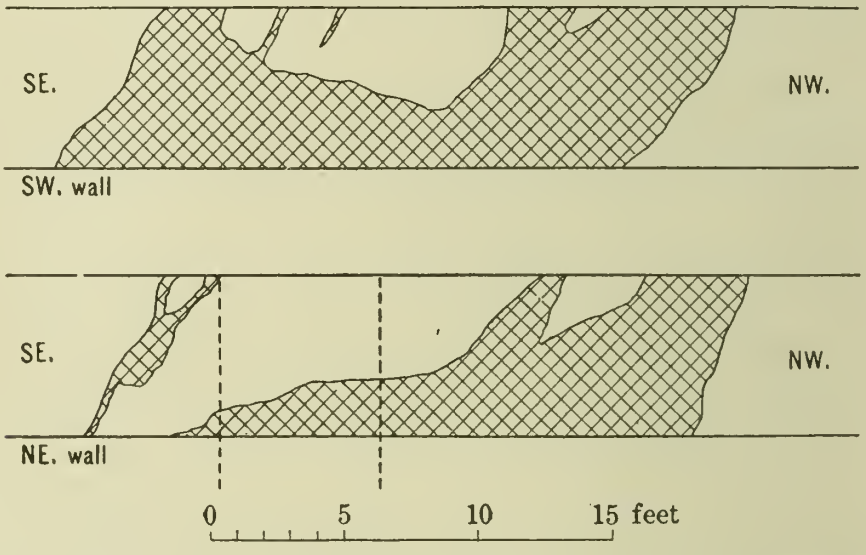


FIG. 6.—Sketch showing form of ore body exposed in the main or northern tunnel at the Bonanza mine.

A better conception of the form of the ore bodies can be obtained by an examination of figs. 5, 6, and 7 than can be given in a written description. The two main parallel surface veins afford only an imperfect idea of the deposit. Those two veins represent a total replacement of limestone along minor zones where shearing was most intense. The two tunnels show that not only is the limestone replaced along the main shear zone, but that mineralized waters followed minor fracture planes also, and thus yielded the low-lying ore bodies and great irregular masses seen underground. Between and around the large masses of chalcocite the limestone was shattered and filled with many small veins of ore, forming a stockwork that is most noticeable in the winze tunnel and on the surface northeast of the main ore body. As a rule the brittle chalcocite is very little fractured. The limestone, on the other hand, is greatly shattered

and is filled with thin veins of calcite, which are older than the ore deposition. Open cavities in the fractured limestone have been filled with ice, and both the country rock and the talus on either side of this ridge are frozen all summer except for a few feet at the surface. The talus slopes below the ore body contain a large quantity of chalcocite resulting from weathering of the veins above and are a valuable source of copper.

It is a suggestive fact that, although the main shear zone of the Bonanza mine extends from the limestone through the thin shale bed into the greenstone below, the large chalcocite bodies, so far as can be determined on the surface, end abruptly at the top of the impure shaly beds forming the lower 50 or 60 feet of the limestone. Copper minerals are associated with the shear zone in the greenstone, but only in small amount. Apparently the impure thin-bedded part of the limestone was a less favorable place for deposition than the purer

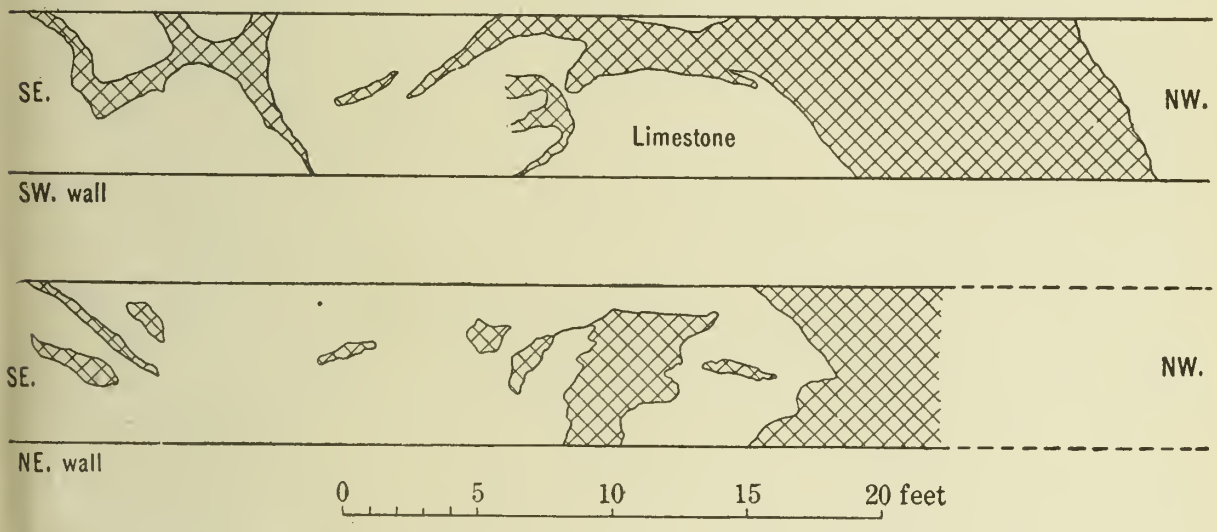


FIG. 7.—Sketch showing form of ore body exposed in the southern tunnel at the Bonanza mine.

massive beds above. This fact has a practical bearing on the quantity of ore present, for it is evident that if the same condition continues underground it limits the downward extension of chalcocite in the limestone. The continuation of the ore body to the northeast will probably be limited chiefly by the continuation of the shear zone in that direction. The exact conditions which determined the deposition of the Bonanza ore body are not known; possibly it was the presence of a shear zone favorable to circulation, but its occurrence together with that of the Jumbo and Erie chalcocite bodies to the northwest indicates that favorable conditions for deposition have been established in more than one place and offer encouragement for seeking other chalcocite bodies at the base of the Chitistone formation.

From the description that has been given it will be seen that there is little on the surface or in the tunnels by which to determine that the ore body has a greater extension from southwest to northeast than

about 400 feet, or, at most, 450 feet, or that it extends down into the basal beds of the Chitistone limestone. It is evident, however, that the Bonanza is an exceedingly rich and unusual body of copper ore.

JUMBO CREEK.

From the Bonanza mine the Chitistone limestone continues northwestward in a succession of lofty cliffs as far as Kennicott Glacier. The base of these cliffs is at the greenstone contact, and in many places contains veinlets and stringers of azurite or chalcocite. In at least two places the quantity of these two minerals, especially of the chalcocite, is such as to make the deposits of commercial importance.

The ore body of the Jumbo claim is 4,600 feet northwest of the Bonanza, at the head of Jumbo Creek, and is located in limestone just above the greenstone-limestone contact on a small southwestward projecting spur or angle of the limestone cliff. South of it and nearly 200 feet below is the glacier in which Jumbo Creek heads and which must be crossed to reach the ore body. The Jumbo and Bonanza ore bodies are at practically the same elevation above sea level, approximately 6,000 feet.

The limestone at the Jumbo is made up near the base of slightly cherty beds ranging in thickness from 8 to 12 inches. The strike is N. 65° W., the dip 35° N. A tunnel 12 feet long was started on the south face of the ridge, 10 feet above the greenstone. The limestone is jointed or cut by minor faults parallel to the bedding and is crossed by veins of calcite from 1 to 2 inches thick. Thin veins of chalcocite and azurite accompany them and fill some of the fractures. Seven feet above the tunnel mouth is the east end of a large chalcocite mass, which is well exposed on the axis of the ridge. As indicated on the surface, this body of ore is a mass of solid chalcocite 30 feet long, 6 feet by 4 feet 6 inches at the west end, and tapering to a diameter of 1 foot at the east end. It appears to be a rudely lenticular or possibly a conical body, but has irregularly shaped protuberances, as may be seen at the west end, where the steep west face or slope of the spur gives a cross section of the ore body. (See fig. 8.)

A little way east of the Jumbo tunnel is a second tunnel in limestone a short distance above the greenstone. The tunnel runs nearly north or slightly to the northeast in limestone that strikes N. 65° W. and dips 25° N. In the tunnel, which is 12 feet long, the limestone is crushed and jointed. Small veins of calcite and azurite up to 2½ inches in thickness fill joint cracks, especially a set of perpendicular minor faults or slip planes running N. 70° W. No chalcocite is exposed in the tunnel, but it is believed that the azurite indicates its former presence. Fifty feet below the tunnel a lenticular vein of

chalcocite, 3 inches thick at its widest part and 3 feet long, was found in the limestone.

Northwest of the Jumbo claim and nearer Kennicott Glacier is another chalcocite body, the Erie, of similar character, that is said to be larger than the Jumbo. This property was not visited by the Survey party, nor was the Independence group of claims visited, which lies 900 or 1,000 feet below the top of the ridge between Bonanza and McCarthy creeks, on the McCarthy Creek side. The vein of the Independence is in greenstone, and is described by Mendenhall[a] as being a fairly persistent fissure vein from 6 to 8 inches wide and trending obliquely to the limestone-greenstone contact. The

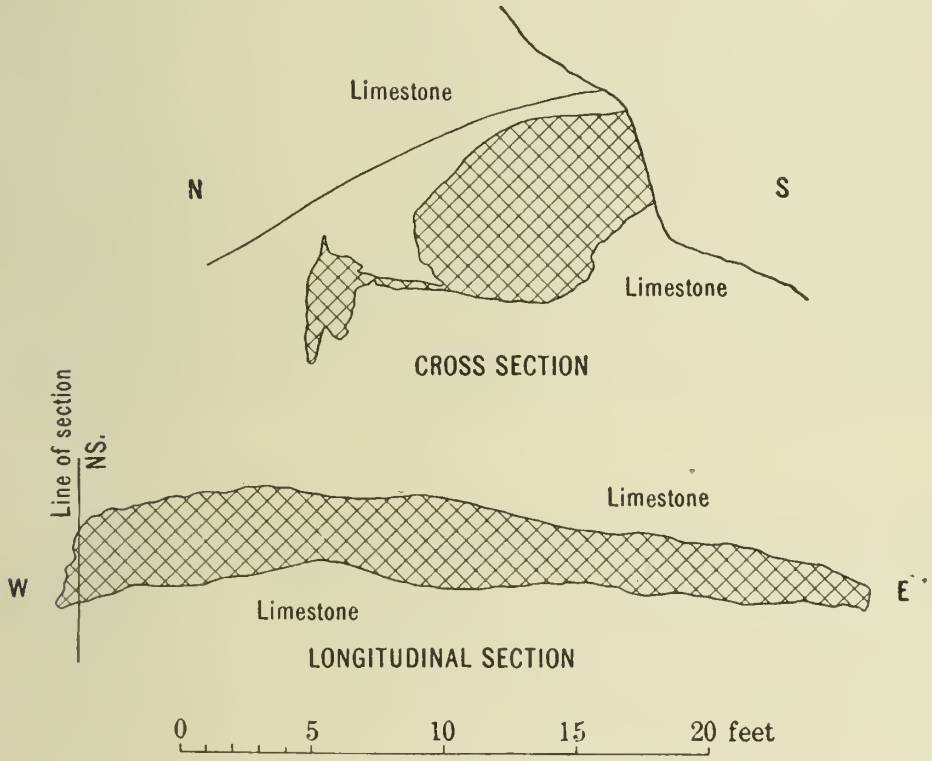


FIG. 8.—Sketch of the ore body at the Jumbo claim.

ERIE AND INDEPENDENCE CLAIMS.

vein mentioned is one of a number that occur in a sheeted zone striking N. 38° E. and made up of a number of small fissures, most of which contain considerable calcite. This zone passes from the greenstone into the limestone, and has its greatest width, about 50 feet, at the contact. The ore is found in the greenstone only, and consists essentially of chalcocite, which fills fracture openings and permeates the greenstone between them. In places the chalcocite is present as amygdaloidal fillings in the greenstone. It is later than the calcite filling of the sheeted zone, and gradually disappears with increasing distance from the zone of mineralization. The main shear zone intersects a system of quartz-epidote veins striking N. 78° E. and carrying

[a]Mendenhall, W. C., Geology of the central Copper River region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1906, p. 104.

a small amount of bornite. Except for the absence of chalcocite bodies in the limestone, there is a marked similarity between the occurrence of copper minerals in this locality and that at the Bonanza.

NIKOLAI CREEK.

The Nikolai mine, on Nikolai Creek, a tributary of McCarthy Creek emptying into Kennicott River a short distance below the glacier, was not visited by the Survey party, as no work has been done there since the claim was patented, and the shaft was reported to be filled with snow and ice. The following description is quoted from the report of Schrader and Spencer.[a]

Nikolai mine.—The Nikolai mine is located on the creek of the same name, tributary to McCarthy Creek from the east. [See Pl. X, *A*.] The occurrence has probably been known to the natives for a long time, and was revealed by an Indian named Jack to Mr. Edward Gates, who, though he had never visited the locality, was able to find it with the aid of a map drawn by Nikolai, late chief of the Taral Indians.

The Nikolai mine is situated 1,000 feet or more above timber line, at an elevation of 4,200 feet. The country rock in the lower part of the creek is Triassic shale intruded by porphyry, but a great fault brings up the Nikolai greenstone, which forms the bed rock from the vicinity of the main forks of the creek to a point above the mine. On the south side of the gulch, opposite the mine, the greenstone is opposed by the unconformable beds of the Kennicott formation, but to the north the Chitistone massive limestone is seen dipping steeply into the mountains, and this is followed by the Triassic shales, covering a large area between McCarthy Creek and Nizina River.

The vein occurs in the greenstone at a horizon not more than 50 feet below the bottom of the limestone, which outcrops in the creek bed a few hundred feet above the shaft. It is a true fissure vein, with well-marked walls, and there has been displacement or faulting along it to the amount of perhaps 50 feet, with the upthrow on the northwest. The course of the fissure varies from N. 50° E. to N. 55° E., and the vein dips about 65° SE. It may be traced for several thousand feet, though it shows no ore on the surface except near the place of discovery. The main fissure is paralleled at a distance of 90 and 140 feet, respectively, by two fissures which, though less prominent, also contain copper minerals, and the rock between is cut by many stringers of ore. In the vicinity of the shaft the main vein has a width of from 8 to 12 feet and is divided about equally by a horse of greenstone 3 or 4 feet across, in which the shaft has been sunk. The ore on either side of the horse is practically pure bornite, with only a small amount of quartz associated in an irregular way. Locally, as shown near the creek bed, there is a band of chalcopyrite lying next to the hanging wall. The development in the latter part of August, 1900, consisted of a shaft 30 feet in depth, and an open cut along the vein for perhaps 50 feet. Throughout this distance ore having a thickness of from 2 to 4 feet had been exposed, and in the bottom of the shaft the horse had been penetrated and bornite ore was found on the foot-wall side. The development has been sufficient to show the presence of a large shoot of ore which can be mined from the present shaft or from a short adit which could be driven to cut the vein at a depth of perhaps 100 feet, but whether the

[a] Schrader, F. C., and Spencer, A. C., Op. cit., pp. 86–87.

A. NIKOLAI VEIN AND SHAFT.

B. VEIN OF HENRY PRATHER CLAIM.

Looking north. Hammer marks foot wall.

ore is generally distributed or whether there are other large ore bodies along its course is yet to be determined.

A good trail, a mile or more in length, has been constructed from the camp at timber line to the mine. During the summer of 1900 about a dozen men were engaged in the exploitation of the Nikolai mine.

CHITISTONE RIVER BASIN.

MAIN STREAM.

Chitistone River is a southwestward-flowing tributary of the Nizina and joins that stream approximately 30 miles above its mouth. It heads in the glaciers which cover the divide between Copper and White rivers, and its valley is one of the routes by which prospectors reach Skolai Pass and the White River Glacier. Between the lower end of the Chitistone Glacier and Nizina River the stream has a length of 18 miles, but the copper properties on which most work has been done are situated within the lower 10 miles of the valley. Within this lower 10 miles Chitistone River flows over a broad gravel-covered flat, ranging in width from one-half to 1 mile. The largest tributaries are Glacier and Toby creeks, both flowing in a northwesterly direction and joining the main stream within 2 miles of each other. The mouth of Glacier Creek, the more westerly of the two tributaries, is 7 miles from Nizina River. The larger tributaries, including two or three besides the two named, have broad gravel-covered valley floors similar to that of the Chitistone itself, but much narrower and with higher gradients. The smaller tributaries tumble down steep, rock-walled gulches.

For more than half its length the valley of Chitistone River is cut in Nikolai greenstone and the overlying heavy Chitistone limestone. In this vicinity the limestone reaches the maximum thickness observed, at least 2,000 feet. South of the river it dips gently northward, forming a conspicuous cap on the greenstone that may be seen for many miles to the southwest, and everywhere it lies at least 1,000 feet above the valley floor. On the north side of the river, between Nizina River and Glacier Creek, the whole mountain mass, except two or three hundred feet at the base, is Chitistone limestone extending to an elevation of more than 4,000 feet above the valley. On the west side of Nizina River the limestone is seen to dip to the north at about 30°, so that the great thickness on the east side represents the central low-lying portion of a large syncline. Farther up the valley Triassic and other younger rocks with granular intrusions and included coal beds appear.

Copper is found on Chitistone River in both the greenstone and the limestone, but in 1907 development had not revealed any considerable ore bodies. On the Chitistone itself most of the work had been done by the Houghton Alaska Exploration Company and by

the Alaska United Copper Exploration Company, the first-named company directing its efforts to prospecting claims north of the mouth of Glacier Creek on the north side of the river and to claims on the south side of the river about 4 miles below Glacier Creek, and the second to prospecting ground on Contact Gulch opposite the mouth of Toby Creek. A large number of claims have been staked, including practically all of the limestone-greenstone contact, but some of them show nothing but the green carbonate stain.

Glacier Creek, among the tributaries of Chitistone River, is at present the area of greatest promise. Native copper is the ore chiefly found.

The property of the Houghton Alaska Exploration Company west of Glacier Creek on Chitistone River, on which most work has been done, lies at the limestone-greenstone contact 1,225 feet above the river valley. A tunnel 20 feet long follows a fault in the limestone running S. 30° E. and dipping 70° to 80° E. This tunnel lies just above the greenstone contact at the top of a large limestone talus slope. Fifteen feet higher and 20 feet farther east is a slope about 25 feet long driven on the dip of a fault parallel to the bedding, which strikes N. 60° E. and dips 35° S. There is a fault zone of crushed country rock which has a thickness of 4 feet on the west side of the slope, but diminishes to 2 feet on the east side and practically dies out at a short distance from the mouth. It can be followed for 15 feet westward and is then cut off by a cross fault, giving it a lenticular cross section with a maximum thickness of 4 feet and a length of about 25 feet. The limestone is further cut by many small calcite veins. The fault zone is heavily impregnated with blue and green copper carbonate, accompanied by epidote. Iron oxide also is abundant in the crushed zone. The copper minerals penetrate the country rock, coating the joint planes with green carbonate, but azurite is almost restricted to the crushed zone.

The central camp of the Alaska United Copper Exploration Company is at the mouth of Contact Gulch, opposite Toby Creek, and most of the summer's work was done in that vicinity, although the company owns many other claims. A large part of the season was consumed in the construction of a cabin and trails by which the prospects, situated over 2,000 feet above the mouth of Contact Gulch, may be reached. Bornite in greenstone is the principal ore, but not enough development has yet been done to reveal any large body of it.

GLACIER CREEK.

Native copper is found on Glacier Creek in a small gulch about 1 mile above the lower end of the glacier, or 6 miles above the mouth of the creek. This copper was known to the Indians, who broke out

fragments from the bed rock. The outcrop is on the northwest side of a steep gulch 625 feet above the glacier and less than half a mile from it. The gulch is reached by a trail over a high rock cliff, by going along the north side of the glacier between the ice and the bank or by crossing diagonally from the south side of the glacier. Traveling along the glacier's side is dangerous because of almost continuous rock slides, and is not possible at all in some seasons.

The country rock is a series of bedded amygdaloidal greenstone flows, and the copper is seemingly restricted to a particular one of these beds. Nearly 75 feet above the creek, on the claim known as the Chiti, the greenstone is cut by a fault running N. 10° E. and dipping 40° W., almost parallel to a bed of greenstone filled with black amygdules, consisting of a mixture of copper oxide and carbonaceous matter, and cut by small veins of the same material. Above and below this bed, whose maximum thickness is 8 feet, is greenstone with quartz amygdules and only a small amount of the black mineral. In the main open cut the fault appears at first glance to form the hanging wall, but there is a small thickness, not over 2 feet, of the black amygdaloidal greenstone just above it. Thirty feet farther north along the strike the fault is at the foot wall, and here the black amygdaloidal rock has its greatest thickness, 8 feet. The main fault changes its direction here and strikes more nearly east and west. It is cut by minor faults and slightly displaced. The black amygdaloidal rock is covered by slide rock 50 feet south of the largest cut, but continues with decreasing thickness northeastward for about 200 feet. The large fault, however, is easily traced for not less than 300 feet.

Copper is present as malachite, native copper, chalcocite, and cuprite. Masses of native copper weighing several pounds are found, but it is present chiefly as small specks in the greenstone and the black amygdules and as thin sheets or leaves of about the thickness of paper and small stringers in the greenstone. The larger masses occur in sponge or netlike form inclosing country rock. The largest one seen in place was not over 8 inches in diameter, but a quartz vein 300 feet north of the main cut yielded a mass weighing about 60 pounds. The fault with traces of the black amygdaloidal rock and some copper are reported to be found still farther to the northeast, but were not followed.

DAN CREEK.

Dan Creek is the first tributary to Nizina River below the Chitistone, from which it is separated by a mountain mass made up of Nikolai greenstone capped by gently northward-dipping Chitistone limestone (Pl. X, *A*). On the northern side of this mountain mass the limestone-greenstone contact at its lowest point is only a few hundred feet above Chitistone River. On the southern or Dan Creek

side, however, it ranges from 2,000 to 4,000 feet above the stream (Pl. X, *B*). A further description of the geography and geology of Dan Creek is given in the account of its gold placers on pages 97-99.

Just below the contact, north of Dan Creek, the greenstone in many places is stained with copper green and contains small stringers and bunches of copper minerals, chiefly bornite. This is said to be particularly true of a zone of greenstone extending for a long distance along the contact and situated about 30 feet below it.

At the head of Boulder Creek, which joins Dan Creek below the canyon, is a claim called the Westover, belonging to the Alaska United Copper Exploration Company. The exposed ore is a mass of bornite at or just above the limestone-greenstone contact. This ore body is entirely in the limestone and is unusual in that the other known similarly situated copper deposits of the eastern portion of the Chitina copper region are chalcocite rather than bornite. The surface exposure has a length, in a horizontal direction, of 30 feet and a maximum width of 8 feet. At one end the ore consists of nearly pure bornite, whose boundaries with the inclosing limestone are rather sharply defined. At the other end it gradually fades into the country rock. No development work has been done other than to clear away the face of the exposure.

GOLD.

THE NIZINA PLACERS.

LOCATION AND HISTORY.

The Nizina placer district, as now known, embraces in a general sense the drainage areas of Dan, Chititu, and Young creeks, which flow into Nizina River from the east and south. Young Creek empties into the Nizina about 20 miles above its mouth, Chititu Creek comes in about 1 mile above Young Creek, and Dan Creek flows into the main river about 4 miles farther upstream.

The discovery and location of these placers in 1902 has been described by Mendenhall and Schrader.[a] After passing through the stampede stage of exploration the Nizina district relapsed into a period during which a great many of the claims as originally located were worked only on a small scale in an unprofitable manner. From one cause or another much of the better ground was soon involved in lawsuits which, until last year, 1906, were not settled in a way to justify systematic work necessitating an investment of capital.

[a] Mineral resources of the Mount Wrangell district, Alaska: Prof. Paper U. S. Geol. Survey No. 15, 1903, pp. 59–61.

A. CONTACT OF CHITISTONE LIMESTONE AND NIKOLAI GREENSTONE.

East side of Nizina River, about a mile below mouth of Chitistone River.

B. LOOKING ACROSS NIZINA RIVER INTO VALLEY OF DAN CREEK.

Chitistone limestone capping Nikolai greenstone on left; Triassic limestone-shale on right.

GEOLOGIC SKETCH.

The bed-rock floor of this area is, so far as known, made up of a series of shales with a few thin limestones that are rather commonly intruded by dikes and sheets of light-colored porphyry. This bed rock on Chititu and Dan creeks is for the most part a dark, fine-grained, homogeneous shale in which there is very little limestone. These shales are hard and closely jointed and have been intricately folded and contorted. They have also been subjected to faulting, some of which is very recent, as it has occurred since the unconsolidated Pleistocene bench gravels that lie unconformably upon the shales were deposited. It is probable that this shale bed rock is the floor upon which rests the thick sheet of bench gravel deposits that, so far as known, appear to extend from the northern slopes of the valley of Dan Creek along the gently sloping mountain sides that form the eastern side of the Nizina Valley to and probably beyond Young Creek. Schrader and Spencer represent the higher mountains to the east as made up of this series of shales and thin-bedded limestone.

The broad depression between the Skolai and Chugach mountains is floored by unconsolidated deposits, whose character and origin have already been discussed. A part of them was laid down in water; another part was deposited without sorting by water. The important deposits of the Nizina region, however, were mainly water laid and include the bench and stream gravels. Of the two the bench gravels are of less present commercial importance, although in amount they greatly exceed the stream deposits.

The general distribution of this thick gravel terrane appears to correspond to the benchlike surface feature that extends along the eastern side of Nizina Valley from Dan Creek to Young Creek and beyond in a southwesterly direction. The gravels apparently have their upper eastward limits about the middle altitudes of the mountain sides. They gradually slope down toward the west to an elevation of about 3,000 feet above the sea level, where the surface descends more abruptly for several hundred feet and thence continues on to the west for 2 to 6 miles as a gradually sloping valley floor to Nizina River, where the elevation is about 1,400 feet.

It is not known to what extent the distribution of the gravels may depend on the configuration of the rock floor beneath them, but considerable topographic irregularities exist both in slope of surface and in surface forms, giving rise to ridges, valleys, and hills such as would be presented by a rolling topography of moderate relief. These topographic features have been factors in the original distribution of the gravels, and their consideration is important in studying the Nizina placers, for the reason that at the present time the evidence

points toward the bench gravels on this older land surface as being the source from which the supply of gold in the present stream or creek gravels is chiefly derived.

The view that the easily worked creek gravels of the present streams have received their gold from a source in the higher bench gravels is amply substantiated by the fact that the presence of gold in the bench gravels has been established. At several localities on Chititu Creek the bench gravels have been prospected systematically by tunnels following the bed-rock surface, and it has been found that gold is present in no inconsiderable amount, and that while the values are naturally highest on or near bed rock, yet considerable gold is present for some distance above bed rock. Under present conditions, however, it does not seem that the bench gravels can be worked profitably, though when supplies and labor can be obtained at lower cost it may prove profitable to mine them by tunnel and drift methods, or possibly by hydraulicking on a large scale. The bench gravels are not frozen, as are similar deposits in some parts of Alaska, consequently in working them by tunnels and drifts it is necessary to timber the workings thoroughly, an item of expense that increases the cost of such operations. It is by no means improbable that there may be old channels in the rock floor underlying these gravels where placer gold has been concentrated in amounts large enough to pay for mining by timbered tunnels and drifts. It may also be found that over some areas the bench gravels are not too thick to be profitably worked by hydraulic methods, even if a considerable thickness of overburden should have to be removed to reach the pay ground. Systematic and thorough sampling of large areas by drilling test holes should precede any contemplated installation for working gravels.

The present stream gravels of Dan, Chititu, and Young creeks are the deposits in which gold was first discovered and on which active operations are now being conducted. They are in part derived from the bench gravels and in part by the cutting of the streams in their own bed-rock channels. These deposits are more fully described in connection with the individual creeks.

The suggestion that the present auriferous creek deposits have been derived from the thick mantle of bench gravels leads to a consideration of the source of the bench gravels and the placer metals they contain. Bowlders, cobbles, and pebbles of greenstone, with a considerable amount of native copper, are characteristic materials of the bench gravels. A few of these copper nuggets weigh more than 100 pounds, but most of them run about 1 or 2 ounces. The nearest known source for the greenstone and native copper of these gravels is on the north side of the valley of Dan Creek, and thence northward in the area of Chitistone River. Here are areas of greenstones in

which some small amounts of native copper are known to occur, but no gold has been reported from these rocks. The following statements are quoted from the report by Mendenhall and Schrader:[a]

> The rocks throughout the greater part of the district are reported by Schrader and Spencer to be the black shales and thin limestones of the Triassic, but in the northern part of the basin of Dan Creek the Nikolai greenstone and the overlying heavy-bedded Chitistone limestone outcrop. There is a doubtful region about the head of Young Creek, where these older rocks may also be found.
>
> The black Triassic shales are reported to be intruded in this region, as they are known to be in other localities, by abundant porphyritic dikes, and the gold may be found to be genetically connected with these intrusives.

So far no facts have been brought to light to show whether the porphyry dikes in the Triassic shales may be a possible source of gold or not. On the other hand, it has been reported by a prospector that free gold occurs in the conglomerates of the Kennicott formation in this region. This formation has been assigned to the Upper Jurassic or Lower Cretaceous, and at present the only rocks of this age known to occur in the Nizina placer area lie south of Young Creek. There is also an area on the west side of Nizina River, opposite the mouth of Chitistone River. The Kennicott formation as now known occurs in isolated areas, of no very great extent, distributed from Kotsina River to the mountains south of Young Creek. It lies unconformably upon the Triassic shales and limestones and older greenstones. This series of conglomerates was no doubt formerly very much more widely distributed than it is at present. Extensive deposits of it have probably been entirely carried away by erosion, and if they were gold bearing, in part or as a whole, it can easily be seen how such a source might have supplied the present bench gravels in the Nizina district.

CHITITU CREEK.

The stream gravels of Chititu Creek (fig. 9) and its tributaries have received the most attention in this district. The upper half of Chititu Creek occupies a comparatively narrow valley that is excavated to a depth of 200 to 400 feet through the thick deposits of bench gravels and exposes the underlying shale. In this shale bed rock the stream has carved a trough from 200 to 700 feet wide and from 10 to 50 feet deep, conforming in slope with the surface of the rock floor. The trough is filled to a depth of 8 to 16 feet by recent stream gravels mainly derived from the adjacent bench gravels. In brief, the whole process has been that of a natural ground sluicing of the bench gravels. The bed-rock flume or sluiceway is paved with bowlders and cobbles, and in the natural riffles thus formed the gold and copper have been concentrated.

[a] Mendenhall, W. C., and Schrader, F. C., Prof. Paper U. S. Geol. Survey No. 15, 1903, p. 61.

Only one of the original locators of claims on Chititu Creek has developed his holdings along conservative and consistent lines from the time of their discovery. On claim No. 11 above Discovery open-cut work was begun with pick and shovel. During the second season canvas hose was used, and finally a small hydraulic plant with giants

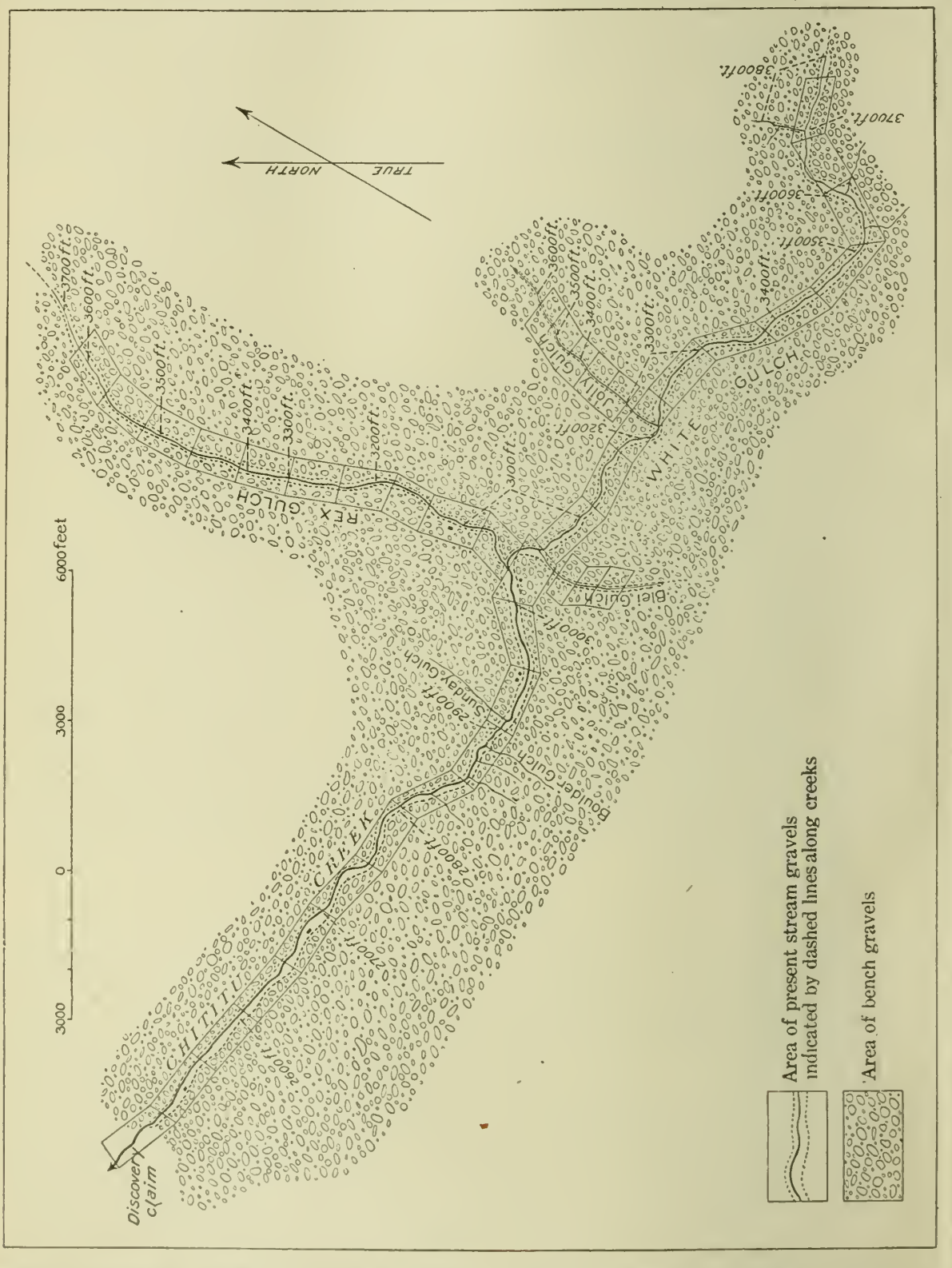


FIG. 9.—Sketch map of a part of Chititu Creek, showing location of claims and relation of bench and stream gravels.

was installed. This plant has been improved from year to year and the results obtained have been increasingly satisfactory to the owner.

In 1907 active development work was begun on a group of claims that includes the major portion of the placer ground on Chititu Creek. A complete hydraulic plant, supplemented by a well-

equipped sawmill run by water power and an electric-lighting plant to aid in night work during the latter part of the open season, was during the winter taken over the snow and ice to Chititu Creek from Valdez, a distance of 200 miles, by means of horses and sleds. This method of transportation is the only way by which any considerable quantity of material can be conveyed into the Copper River region at the present time. Even when economically conducted, on a large scale involving quantities of 100 tons or more, such transportation from Valdez to the Nizina district has never cost less than $130 per ton. On small shipments the cost may be as much as $400 per ton.

The greater part of the open season of 1907 was spent in installing this plant on the lower eight claims on Chititu Creek. The sawmill was erected on claim No. 4, above Discovery, to supply lumber for flumes, buildings, and other purposes. A large amount of hydraulic pipe was riveted together from the separate sheets, and as the season progressed the whole plant, with dam and headgates on claim No. 8 above, the flume and pipe lines, lighting plant, etc., was assembled in working order, so that by the close of the season all arrangements were completed for beginning active mining on claim No. 1 with the opening of the season of 1908.

DAN CREEK.

Dan Creek, in point of size, is the first important tributary to Nizina River above Chititu Creek, and, as has been previously stated, is also the first one below Chitistone River. Its general course is west-northwest, and it joins the Nizina at the point where that stream, flowing southward from the Skolai Mountains, abruptly changes its course to the west. The drainage area of Dan Creek covers approximately 45 square miles and is nearly as broad as it is long.

The stream for a distance of nearly a mile below the place where it emerges from the mountains flows across the gravel floor of the Nizina River valley, but is raised slightly above it by the broad, low, fan-shaped deposit of gravels it has brought down from above. The valley above this portion of the stream presents three different topographic features. For nearly 2 miles Dan Creek has cut its way through the deep bench gravels bordering the Nizina Valley and has excavated a shallow trough in the country rock. In this narrow trough the stream gravel is laid down. Above this portion the channel is in a narrow box canyon, which finally expands into the more open basin-like upper valley. Two principal branches unite above the canyon to form the main stream. The northern branch retains the name Dan Creek; the other is known as Copper Creek.

The bed rock, as naturally exposed or as uncovered by mining operations along the lower part of Dan Creek, is made up of Triassic shales

intruded by light-gray porphyritic and greenstone dikes. These shales, so far as is now known, occupy most of the area south of Dan Creek to Chitina River. North of Dan Creek is the Nikolai greenstone, overlain by a heavy capping of Chitistone limestone that forms the top of the mountain mass between Dan Creek and Chitistone River (Pl. X, *B*). The unnatural position of the Triassic shales south of the stream with reference to the greenstone north of it is believed to have been brought about by a great fault extending through the valley from southeast to northwest and removing from view the Chitistone limestone which normally should be present between the greenstone and shales. This fault continues northwestward at least as far as Lakina River.

Placer mining is at present restricted to the areas above and below the canyon. Above the canyon most work has been done on Copper Creek. This part of the stream is difficult to reach with supplies, and only a few men were at work there in 1907. Most of them were doing nothing but assessment work, and yet a few thousand dollars in gold have been produced during the several years since work began. The creek claims below the canyon are under one control, and, though the gold production has not been large owing to the difficulty of working the ground, prospecting has shown that gold is present.

Placer gold is associated with two classes of deposits, the present stream gravels and the older and much more extensive bench gravels. Mining or prospecting has been carried on in both of these. Undoubtedly a great part of the gold in the present stream is a concentration from the benches through which the creek has cut its channel. Whether any part of it has been brought by the present stream directly from its original source—that is, a source other than the higher unconsolidated bench gravels—to the place it now occupies, was not determined.

The first claim below the canyon is No. 7 and the numbers decrease downstream. Near the camp a cut approximately 400 feet long and as wide as the shovelers could work at one setting of the boxes was made in the creek gravels of claim No. 5. Directly above is a larger cut nearly as long and averaging about 75 feet in width. The bed rock is hard, close-jointed shale cut by dikes of light yellowish-gray porphyry and of greenstone. The gravel and its slight soil covering range in thickness from 8 to 12 feet. The gravel consists in part of shale fragments and contains a large percentage of greenstone and porphyry. Some of the bowlders in the large cut have diameters as great as 4 feet and many of them average 10 or 12 inches in maximum diameter. All of this material has been more or less rounded by stream action. It is poorly bedded, and spruce logs and fragments of wood are buried in it. The large cut was made by piling up a wall of bowlders along the gravel face, thus forcing the creek water

to undercut the bank and cause it to cave. Bed rock was then cleaned by hand. Such work is expensive, as it requires several handlings of all the larger material. A third cut, 300 feet long and one box wide, on claim No. 6 showed gravel and bed rock of the same character.

The width of the stream gravels is not great, in places not over 100 or 200 feet, but it increases down the creek. On each side benches of gravel close to the stream rise to a height of several hundred feet. Tunnels in these benches have demonstrated that they carry gold. One of these tunnels on the upper end of No. 6 or the lower end of No. 7 had a length of 72 feet. It was driven along the rock floor upon which the gravel rests and is 10 feet higher than the present stream. In other words, the creek has here cut 10 feet into the bed rock since the present drainage was established. The tunnel was driven in winter as a prospect and yielded good values in gold.

The Dan Creek gold from the gravels below the canyon is coarse and smooth. Most of it is flat, and the heaviest of it is found either on bed rock or within 2 feet of it. It is accompanied by placer silver and placer copper. Nuggets of silver and copper, such as are called "half breeds" in the Lake Superior region, are frequently found here and on Chititu Creek also. Copper is associated with both the creek and the bench gravels in pieces ranging from the size of shot to masses of 100 pounds or more. Only recently has any effort been made to secure the copper, as it is of no value with the present means of transportation. Most of the operators are now saving it, however, and when railroad transportation is available the returns from the copper may be found to reduce considerably the cost of mining.

The gold from Dan Creek above the canyon differs from most of that below in that it is generally rough and not flattened, indicating that it has not been hammered out and worn so much by moving bowlders.

Surveys for a hydraulic plant on the lower end of Dan Creek have been made, and it is expected that the installation of the plant will be begun during the summer of 1908.

REALGAR.

About one-third of a mile down Fourth of July Creek from the Bekka and Eli claims there is an occurrence of realgar (sulphide of arsenic). The mineral fills small spaces in a crushed zone in thin-bedded limestones. Some of the spaces are filled for a width of 1 to 2 inches with well-formed crystals, but other seams contain the realgar in a more impure earthy form. The rest of the shatter spaces of the limestone are largely filled by thin seams of calcite. No considerable amount of realgar appears to be present at this place.

COAL.

On the divide between Fourth of July and Bear creeks, north of the pass crossed by the trial, at elevations of 5,800 to 6,000 feet, is a small patch of coal-bearing shales and flaggy arkosic sandstones covering an oval-shaped area of about 20 acres. The thickness of these beds is probably not over 50 feet. They are partly covered by more recent andesite lava, that occupies a smaller area and stands at its highest point as a pinnacle about 50 feet high. These rocks, which may be provisionally assigned to the Tertiary, appear not to have been involved in the major fault that is well exposed on the head of Fourth of July Creek, which brings the Nikolai greenstone and Chitistone limestone to the north, against the thin-bedded limestones and shales to the south. The Tertiary coal-bearing beds seem to lie in a nearly horizontal position on top of the inclined beds of the older series. The coal was not seen in place, its presence being indicated only by small weathered fragments mixed with the disintegrated shales. It is probably not of workable thickness; and if it were, the small amount and its inaccessibility would prevent it from becoming of commercial importance.

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U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC RECONNAISSANCE MAP AND SECTIONS OF THE CHITINA COPPER BELT, ALASKA

BY F. C. SCHRADER, ARTHUR C. SPENCER, F. H. MOFFIT, AND A. G. MADDREN
1900 AND 1907
Alfred H. Brooks, Geologist in charge
Topography by T. G. Gerdine and D. C. Witherspoon.

Scale 1/250000

5 0 5 10 15 miles
5 0 5 10 15 20 kilometers

Contour interval 200 feet
Datum is mean sea level

1908
ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

LEGEND

SEDIMENTARY ROCKS

- Qg — Gravels, boulders, clay and silts
- Jk — Kennecott Formation
- Tr — Shales and limestones
- Trc — Chitistone limestone
- ? — Conglomerates etc.

UPPER JURASSIC OR QUATERNARY
TRIASSIC
UNKNOWN

IGNEOUS ROCKS

- V — Tertiary volcanics
- a — Andesite
- d — Diorite
- g — Gabbro
- p — Porphyritic intrusives
- ng — Nikolai Greenstone

TRIASSIC OR CARBONIFEROUS

Faults

Strike and dip

Glaciers

SECTION ALONG LINE A-B

SECTION ALONG LINE C-D

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

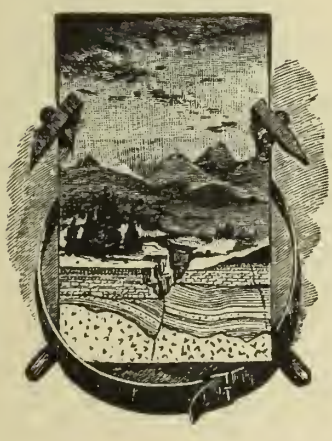
BULLETIN 375

THE FORTYMILE QUADRANGLE

YUKON-TANANA REGION ALASKA

BY

L. M. PRINDLE



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GOVERNMENT PRINTING OFFICE
1909

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PREFACE.

By Alfred H. Brooks.

In planning the surveys and investigations of Alaska the attempt was made to cover first those regions which were of the greatest economic importance. As a result many of the mapped areas are very irregular in outline, and it was found desirable to introduce greater uniformity into the published maps as rapidly as the data available for their preparation would permit. With this end in view there has been projected a system of maps covering quadrangular areas outlined by parallels of latitude and meridians of longitude, this being in conformity with the Geological Survey's practice in making surveys within the United States proper. But as the Alaska surveys are for the most part of a reconnaissance character and the region is very thinly populated, it has seemed best to adopt a map unit larger than that used in the States. This unit will include 4 degrees of longitude and 2 degrees of latitude, making a map about as large as can be conveniently handled. It is hoped that eventually all these published reconnaissance topographic maps can be accompanied by sheets showing the geology and the economic resources, but in view of the great demand for the topographic maps it has been deemed advisable to publish some of them immediately in connection with such accounts of the geology and mineral resources as may be available. Nor is it deemed desirable in all cases to delay the issuing of maps until the areas have been completely covered.

The following report, with its accompanying maps, is the third of this series to be issued, and, like the others, covers a part of the Yukon-Tanana region. Others will be published as fast as the accumulation of the field notes will permit. The topographic surveys on which the maps are based were made under the direction of E. C. Barnard in 1898. This is the first of this series of publications which is accompanied by a geologic reconnaissance map on the same scale as the topographic map, and it therefore marks a distinct advance over those previously issued. The geology, however, is treated in the same

general way as in the previous reports, the complete analysis of the many intricate problems being deferred until more facts regarding the phenomena have been collected.

The mapping was done by Mr. Prindle between the years 1903 and 1907. In 1903, 1904, and 1905 he traversed portions of the area, and in 1907 he spent several weeks in studying the rocks exposed along Fortymile River. The work of a number of other geologists has also been utilized in the preparation of the map and report.

THE FORTYMILE QUADRANGLE, YUKON-TANANA REGION, ALASKA.

By L. M. Prindle.

INTRODUCTORY STATEMENT.

The Fortymile quadrangle is delimited by meridians 141 (which is the international boundary) and 142 and parallels 64 and 65. The

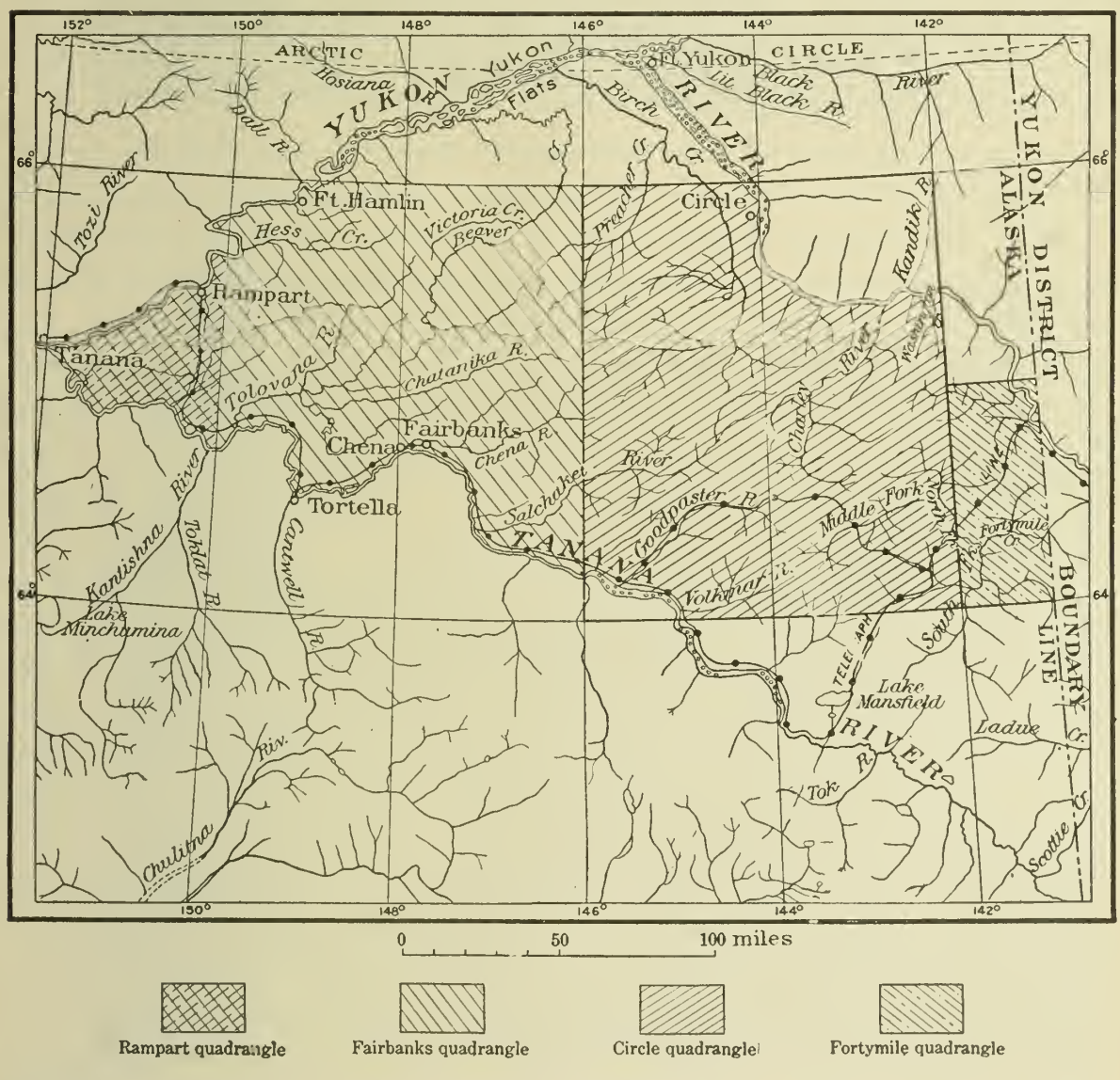

FIGURE 1.—Index map showing location of quadrangles in the Yukon-Tanana region.

area is about 70 miles long from north to south and 30 miles wide. The relation of this quadrangle to the other quadrangles of the Yukon-Tanana region is shown in the index map, figure 1.

Placer gold was discovered on Fortymile River in 1886, and within a few years gold was being produced from many creeks within the limits of the quadrangle. The subsequent discovery of other placer deposits withdrew men from the Fortymile region, but gold has been mined there continuously since the time of its discovery. New productive areas have been developed, and the old areas have been worked by new methods until the ground available for work by the methods hitherto employed is largely exhausted. With a gradual decreasing annual production that reached in 1907 about $150,000, the introduction of methods capable of handling cheaply large quantities of ground has been rendered imperative to meet the conditions that now prevail. Such methods have been in use for several years in the Dawson region, and the results attained there by dredging have been influential in the determination of methods to be employed in the Fortymile region, where the conditions are in many respects similar. The most important item of mining development in the Fortymile region in 1907 was the introduction of dredges and experimentation with this method.

The investigations of the Geological Survey have helped in the development of the district. On account of the growing importance of the Yukon-Tanana region a party consisting of Spurr, Goodrich, and Schrader investigated the placers of the Fortymile, Birch Creek, and Rampart districts in 1896.[a] The Fortymile quadrangle was mapped topographically by E. C. Barnard in 1898 on a scale of 1:250,000, or about 4 miles to the inch. The district was traversed by the Peters and Brooks party during the fall of 1899 on their trip from Pyramid Harbor to Eagle.[b] In connection with the systematic survey of the Yukon-Tanana region, begun in 1903, the areas adjoining the Fortymile district have been topographically mapped on the same scale as that of the accompanying map (Pl. IV, in pocket), and geologic reconnaissance trips have been made by the writer through the country lying between Yukon and Tanana rivers. All the producing creeks were visited in 1903; in 1904 and 1905 portions of the quadrangle were traversed, and in 1907 the areas adjacent to the Fortymile were visited.

As a result of these various trips, a body of material has been gathered bearing on the geology and mineral resources of the Fortymile quadrangle which has not yet been altogether correlated and studied in detail. Geologic surveys have not been carried on systematically throughout the quadrangle with the idea of mapping it areally as a unit, but have been largely incidental to the other work,

[a] Spurr, J. E., Geology of the Yukon gold districts, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 87–392.

[b] Brooks, Alfred H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska, including description of the copper deposits on the Copper and Tanana rivers: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 331–391.

A. VIEW UP AMERICAN CREEK.

B. VIEW UP WADE CREEK.

and consequently there are many areas that have not been under observation. It is believed, however, that there are sufficient facts at hand upon which to base a preliminary outline of the geology and gold resources of this region—an outline justified by the demand on the part of the mining interests for information of this character. The material is being studied in more detail, and a comprehensive discussion of the problems involved is reserved for the report on the geology of the entire Yukon-Tanana region that is in preparation.

GEOGRAPHIC SKETCH.

RELIEF.

The topographic map expresses, by means of the contour lines, which represent lines of equal height above sea level, the form of the surface of the country. A study of the map (Pl. IV) shows that the region in general is not characterized by definite topographic trends, but rather by undulating, more or less flat-topped, ridges uniform in height and trending in various directions. The flat-topped character is shown in Plate II, *B*. There are a few isolated prominences, locally known as domes—Fortymile Dome and Steele Dome, for example—and in the northwestern part of the quadrangle the ridge of Glacier Mountain, with its rough outline, accentuates the resistant character of the rock composing it. But the predominant characteristic of the country is one of uniformity. This is further emphasized by the valleys. They have been cut to about the same level below the ridges, and those of streams of about the same size are similar. The highest points of the area are in Glacier Mountain, where an altitude of 6,000 feet is attained. The Yukon at Eagle is about 800 feet above sea level. The altitude of most of the ridges is about 3,000 feet. The valleys in general are about 1,500 feet below the ridges.

DRAINAGE.

The map shows the extensive ramification of the drainage units and the complexity of their intergrowths. The valleys have been formed by the streams that flow in them. The drainage of the northern third of the quadrangle is to Yukon River, and, acting on an area of relatively high relief adjacent to a major stream, has formed deep, narrow, high-grade valleys. Fortymile River, formed by the union of North and South forks, receives all the drainage from the southern two-thirds of the quadrangle. The narrow, deeply cut character of the Fortymile Valley is present also in the lower valleys of its tributaries.

The valleys in general maintain their depth nearly to the head, where there is an abrupt descent from the level of the ridges. The upper portions of the valleys are narrowly V-shaped (Pl. I, *A*),

and in a few this characteristic persists nearly to their mouths. Ordinarily, however, the streams have developed a stream flat a few hundred feet in width, rather sharply differentiated from the lateral slopes (Pl. I, *B*). It is frequently the case that the slope forming one side of a valley rises abruptly from the valley floor, while the other slope merges gradually with the level of the ridges. This habit produces an unsymmetrical cross section of valley, which is very common throughout the Yukon-Tanana region. The grade of portions of the smaller valleys where mining is in progress ranges from less than 80 to more than 100 feet to the mile. The grade of the Fortymile within the limits of the quadrangle is probably about 6 feet to the mile, and that of the Yukon somewhat in excess of 1 foot to the mile.

The streams are shallow and rather swift, and most of them are cutting bed rock through a large part of their valleys. The Fortymile, draining as it does large areas outside of the quadrangle and receiving several large tributaries within the quadrangle, is the largest stream and carries the largest quantity of water. Notwithstanding the abundance of water, the swiftness and shallowness of the stream render it difficult of navigation even for poling boats. The Seventymile is comparable in size to Dennison or Mosquito Fork, and carries at ordinary stages sufficient water to enable small boats lightly loaded to reach nearly the western limit of the quadrangle. All the streams except the Fortymile are easily fordable on foot at ordinary stages of the water. The quantity of water in all the streams is subject to great variation from the fact that there is a direct relation between the amount of water carried by them and the rainfall. The ground being for the most part permanently frozen, the greatest part of the rainfall finds its way rapidly to the streams, which soon remove it. A few days of dry weather consequently influence very appreciably the water level in the streams and quickly reduce below the required amount the quantity available for mining purposes in the smaller streams.

The drainage of the quadrangle might be called homogeneous from the fact that most of the streams head at about the same level and that equal streams are cut to about the same depth and have approximately the same grade. This homogeneous character of the drainage has an economic bearing when the necessity of increasing by artificial means the water supply at any given point arises. The absence of commanding ridges with abundant water supply at higher levels renders it necessary, in advancing any undertaking that involves an artificial increase of the water supply, to draw upon similar units of drainage, and the differences in elevation are so slight that, in order to obtain the efficiency available in such narrow vertical

A. CANYON OF FORTYMILE, 500 FEET BELOW THE LEVEL OF THE OLD VALLEY.

B. FLAT-TOPPED RIDGE OF QUARTZITE SCHIST.

Between Davis and Poker creeks. Altitude approximately 3,800 feet.

limits, careful preliminary measurements of water supply and grades are required.

A characteristic of many valleys in the Fortymile quadrangle is the presence of benches at various heights, from a few feet to more than 500 feet, above the present level of the streams. These are a part of the great system of benches present throughout the greater part of the valley of the Yukon and those of its tributaries, and mark different stages of stream development. The significance of these benches lies in the fact that streams have a tendency to register a long-continued maintenance at a certain level by the development, through lateral cutting, of an approximately level bed-rock floor of considerable width upon which stream deposits are in the course of time deposited. With renewed opportunity for downcutting, a canyon may be cut below the level of this floor, like that of the Fortymile below the floor of the old valley of the Fortymile that is so prominently developed as a high bench throughout the portion of the Fortymile Valley included in the quadrangle. Pauses in the process of downcutting are duly indicated by benches of intermediate height. The high bench and present canyon of the Fortymile are shown in Plate II, *A*. The benches are particularly well developed in the valley of the Fortymile and the adjacent portions of the valleys of its tributaries and along parts of the valley of the Seventymile. Attention has long been directed to the benches from the fact that the stream deposits left upon some of them have proved to be richly auriferous.

CLIMATE AND VEGETATION.

The latitude of the area entails strongly contrasted seasons and a wide range of temperature. The summers have the variability characteristic of those in many parts of the States. Some of them are very warm and predominantly dry; in others, rain is frequent and abundant. Their shortness is compensated by the great number of hours the sun is above the horizon. The temperature has an annual range of about 133° F. The maximum attained is about 90° F. and the minimum about —75° F. The following table shows temperatures observed at Eagle:[a]

Maximum and minimum temperatures observed at Eagle.

	Maximum.	Minimum.		Maximum.	Minimum.
	°F.	°F.		°F.	°F.
January	23	—75	July	82	31
February	38	—74	August	80	24
March	56	—56	September	78	8
April	59	—12	October	68	—28
May	82	10	November	39	—52
June	87	26	December	39	—68

[a] Brooks, Alfred H., and Abbe, Cleveland, jr., The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 158–161.

The dates upon which the observations were made were as follows: October, 1882, to May 9, 1883; August 22, 1884, to May 12, 1885; August 16, 1885, to May 19, 1886; August 15, 1899, to December, 1900; November and December, 1901; February to December, 1902.

Frosts are uncommon between May 15 and the end of August, and the conditions are favorable for an abundant growth of vegetation. The precipitation is low, an average of 11.35 inches having been reported from Eagle.

The climatic conditions have an important economic bearing. The Yukon becomes lower and clearer as the time for the freeze up approaches, and closes to navigation at dates ranging from about October 10 to November 20. A thickness of approximately 6 feet of ice is formed, which does not break up till about May 10 to May 20. Much of the ground is permanently frozen, but notwithstanding the extreme cold there is much water in the ground throughout the winter. The water in the streams frequently breaks through and overflows ice already formed, and although quickly frozen is a source of troublesome and expensive delays where streams are used as routes of winter travel. Constant repetition of this process in the smaller valleys results in the accumulation of such a thickness of ice that it lasts till late in summer and interferes with the work of mining. Dams, mining equipment, and roads may be buried beneath such accumulations of ice and rendered valueless. This process of glaciering is so characteristic of the region that it must be provided against in construction work.

The spruce is the predominant tree, but aspen and birch are common, and there is a thick growth of alders and willows along many of the streams. Spruce is abundant and of considerable size in the valleys of the larger streams, and throughout the area it covers the slopes as high as the climatic conditions permit, and the lower ridges in the vicinity of the main drainage lines are covered with it, together with a small proportion of birch (fig. 2). Dwarf birch and scattered bunches of alders are common on the higher ridges. The spruce is of sufficient size to furnish a limited quantity of logs 12 to 15 feet or more in length and a foot in diameter. It has been used generally for sluice boxes and to some extent for dredge building.

Food for stock is rather plentiful and sufficient for forage purposes in many of the valleys. Timber for fuel has proved abundantly sufficient up to the present time.

The well-nigh universal covering of moss retains the frost in the ground, but by stripping away the moss where there is sufficient soil and by repeated cultivation ordinary vegetables can be grown in abundance. At the present time a large part of the supplies of the road houses in the Fortymile quadrangle are furnished by the gardens, and nearly every miner has a small patch of ground under cultivation.

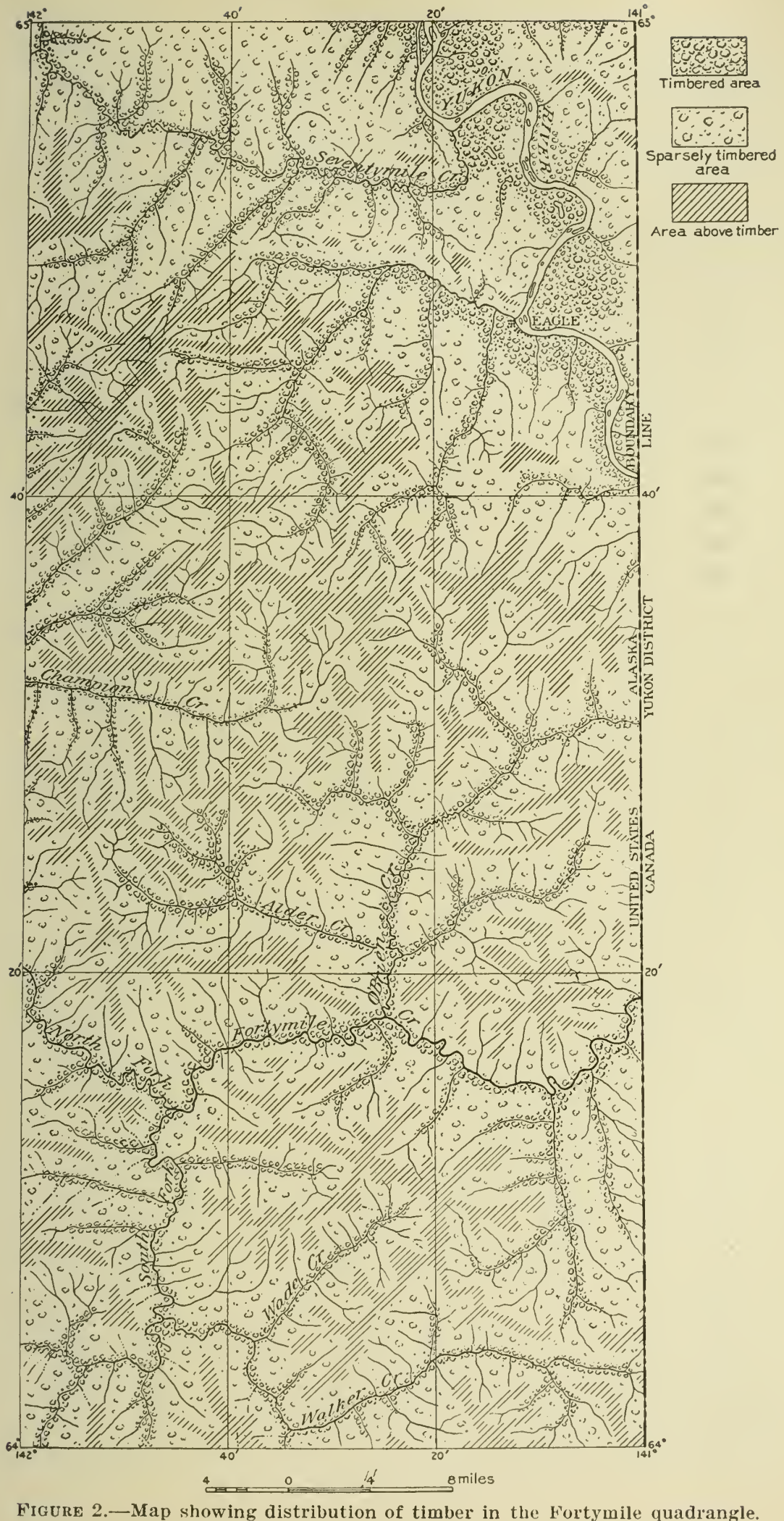

FIGURE 2.—Map showing distribution of timber in the Fortymile quadrangle.

TRANSPORTATION.

Transportation of supplies to the localities where mining is in progress has always been a time-consuming and expensive process. Eagle is the main supply point on the Alaskan side of the boundary, but many of the localities are so situated that it has hitherto been more feasible to procure supplies from Dawson on the Canadian side. Most of the supplies for the Fortymile area are purchased in Dawson and freighted up the Fortymile on the ice by horse sleighs during the winter months. The Fortymile affords access to the remote tributaries where work is being done, but is a roundabout road, and the overflows to which it is subject are often an additional source of delay. Several hundred tons of dredge material were shipped by this route during the winter of 1906–7, when the freight rate to the vicinity of Franklin Creek was about $70 per ton. Summer freighting on the Fortymile is done by poling boats, but it is a difficult stream to navigate even by this method. Long reaches of quiet water are separated by bed-rock riffles where the water is swift and shallow. Supplies are frequently lost or long delayed by low water, and the rates from Fortymile Post on the Yukon to Chicken Creek—the farthest locality to which supplies are carried by this method—is 25 cents per pound (1907). The Canadian wagon road from Dawson to Glacier—a distance of about 60 miles in Canadian territory—is utilized during the summer to a certain extent for the transportation of supplies to creeks on the Alaskan side in the vicinity of the boundary.

The road commission has surveyed a government wagon road from Eagle to the Fortymile country and has already completed about 9 miles of it, from Eagle to American Creek. It is hoped by the construction of such a road to bring Eagle into closer relations with the Fortymile country. Work is also being done by the commission on a road that will make the Seventymile area more accessible from Eagle. In the fall of 1907 a road was in process of construction from the head of Canyon Creek to Walker Fork, in order to avoid the long haul up the Fortymile.

The mail route from Eagle to Valdez passes through the Fortymile country and affords a mail service to the miners of that country. The mail is carried by pack train during the summer season, and in consequence of the large mail-order business the facilities are generally overtaxed.

There are stations of the Government telegraph line at Eagle, at North Fork, and at Kechumstuk, both the latter localities being outside the limits of the quadrangle. The installation of a telephone line has been under discussion by the miners, and a system connecting all the creeks with the supply points would be of great service.

INTERNATIONAL BOUNDARY.

Work was commenced in 1907 on the location of the international boundary southward from the Yukon. A topographic map of the country for 2 miles on each side of the boundary is being made by representatives of both Governments and will afford definite information to the miners as to the position of the line.

GEOLOGIC SKETCH.

STRATIGRAPHY.

INTRODUCTION.

The Fortymile quadrangle is composed of a group of highly metamorphosed rocks, predominantly schists and limestone, assigned provisionally to the pre-Ordovician;[a] of Paleozoic rocks, including phyllites, limestones, and greenstones belonging to the Devonian and shales, slates, limestone, sandstone, and conglomerate belonging to the Carboniferous; of clays, lignite, sandstones, and conglomerates belonging to the Tertiary; of Pleistocene and Recent bench gravels and stream gravels; and of intrusive igneous rocks, some of which have been metamorphosed.

The vertical distribution of the rocks is shown in the table on page 16; their areal distribution is shown on the geologic map, Plate V.

The quadrangle is not one of a few well-defined formations maintaining constant characters over areas of considerable extent, but one in which there is wide variation of material within narrow limits. The different formations possess a heterogeneity of lithologic character which their representation on the map does not express, and their frequent occurrence in small areas necessitates detailed field treatment of the quadrangle that has not yet been given to it. Furthermore, the complexity of the rocks of sedimentary origin has been increased by their metamorphism and intrusion by igneous material, and the igneous rocks also occur largely in areas so small as to be easily overlooked in reconnaissance work. The stratigraphic succession and the distribution of the rocks indicated on the geologic map are therefore generalized to a certain extent, but it is believed that they express with a fair degree of accuracy the geologic relations of the material occurring in this quadrangle.

An inspection of the geologic map shows that the metamorphic rocks form nearly the whole of the southern half of the quadrangle and that the northern half is composed predominantly of Paleozoic

[a] The rocks designated pre-Ordovician include those to which the names Birch Creek and Fortymile have been given by Spurr and Nasina by Brooks. It is not desirable in this report to enter into a detailed discussion of the nomenclature and correlation of the schists. This is one of the most important problems of Yukon-Tanana geology and is to be treated fully in a later report on the geology of the region.

rocks and more recent sediments. Paleozoic and more recent sediments occur also in the southern part of the quadrangle, and local areas of these rocks have perhaps been included within areas assigned on the map to the metamorphic rocks. The data regarding the rocks below Eagle are taken from the work of Brooks and Kindle.[a]

Provisional tabular statement of stratigraphy of Fortymile quadrangle.

System.	Series.	Formation.	Lithologic character.
Quaternary	Recent		Stream gravels and silts.
	Pleistocene		Bench gravels.
Tertiary	Eocene	Kenai	Clays, sandstone, lignite, shales, and conglomerates.
Carboniferous		Nation River	Gray shales with heavy conglomerate beds and some sandstone.
		Calico Bluff	Black and gray shales and slates with some limestone beds.
Devonian			Slates, phyllites, quartzites, cherts, limestones, greenstones, and tuffs.
Pre-Ordovician			Quartzite schist, quartz-mica schist, carbonaceous schist, hornblende schist, gneisses, and crystalline limestone.

PRE-ORDOVICIAN.

Under the provisional designation pre-Ordovician is included here a complex of crystalline rocks, some of which are very definitely of sedimentary origin and some of which are as definitely of igneous origin. Through metamorphism, however, the original constituents and structures have been largely replaced by new constituents and new structures and in some of the rocks the distinctive character of their mode of origin are practically obliterated. The complex at the present time, therefore, is a unit in the sense that all the heterogeneous materials of which it is composed, having undergone the processes of metamorphism, exhibit certain general characters due to these processes and have thus attained a partial homogeneity that affords a basis in the area under discussion for the separation of this group from others. The rocks composing it are regarded as the oldest in the quadrangle. Where the original composition has been similar to that of the overlying rocks and where metamorphism has not expressed itself forcibly it is very difficult to delimit this complex precisely from the later formations.

The area covered by these rocks in the Fortymile quadrangle is only a small part of that occupied by them in the Yukon-Tanaña region. The types represented include quartzite, quartzite schist, calcareous quartzite schist, quartz-biotite schist, garnetiferous mica schist, hornblende schist, carbonaceous schist, crystalline limestone, biotite gneiss, hornblende-biotite-plagioclase gneiss, and biotite augen

[a] Brooks, Alfred H., and Kindle, E. M., The Paleozoic and associated rocks of the upper Yukon, Alaska: Bull. Geol. Soc. America, vol. 19, 1908, pp. 255–338.

A. SCHISTS WITH THIN GRANITIC SILL ON TRAIL FROM WADE CREEK TO WALKER FORK.

B. CONTORTED SCHIST ON RIDGE NORTH OF MOSQUITO FORK.

gneiss. In most of the schists garnets are common, and epidote is very abundant in both schists and gneisses. All of these rocks occur in frequent alternation over large areas. Along the Fortymile from Franklin Creek to the boundary there is exhibited a constant succession of these recurrent types. The crystalline limestones occur interbedded with the schists in beds from a few inches to a hundred feet or more in thickness, being in close contact on either side with quartzite or quartz-biotite schist or with hornblende feldspathic schists or gneisses. At some localities very pure quartzites occur associated with the limestones, and at other localities there are quartzites that contain a considerable admixture of calcareous material.

The structure is very complex. The rocks have been very closely folded (Pl. III, *A*). In places they are apparently nearly horizontal, but here and there such horizontality is the result of the overturning of the folds to a nearly horizontal position. In general the attitude is highly inclined and the dips and strikes vary greatly within small intervals, closely appressed folds being common and pitching in many places at high angles, the pitch of minor folds becoming in places, so far as observable, practically vertical. Shearing has been extensive, and through the shearing of highly pitching folds of thin-bedded quartzite and alternating beds of mica schist rods of quartzite a foot or more in length with elliptical cross sections an inch or more in longer diameter have been developed. In a weathered cross section of such beds the eyes of the quartzite in a micaceous matrix present the appearance of pebbles in a metamorphosed conglomerate. The complicated folding which these rocks have undergone precludes any estimate of thickness.

The structure and composition of these rocks have been further complicated by the intrusion of a large amount of igneous material, some of which has been so closely incorporated with the schists as to be not easily recognizable as of different origin. Innumerable small dikes and sills (Pl. III, *A*), which have permeated these rocks and have in part been folded with them, are reduced to lenticular masses ranging in size from the minute remnants of a crumpled sill a quarter of an inch or less in thickness to the more massive fragments of a sill a foot or more in thickness. Crosscutting dikes have given off minute sheets of thin material along the structural planes of the schists or gneisses until a considerable proportion of the rock has become granitic in composition. There is also much material of intermediate composition, and basic dikes are common. In a word, it would seem that the intimate intrusion of this complex of schists is indicative of their proximity to large masses of igneous material, to which, perhaps, a large part of their metamorphism and a part of their complex structure are due.

The distribution of these rocks is approximately shown on the map. The boundaries indicated have not been traced out on the ground to their entire extent, and must be regarded only as provisional. It is probable that small areas of younger rocks have not been differentiated. Besides the large area of these rocks that form predominantly the southern half of the quadrangle, there is a small area appearing in the upper part of the Seventymile Valley, from the falls to the boundary of the quadrangle. A narrow ridge of undetermined extent, probably to be correlated with these rocks, is located at the base of the ridge limiting Mission Creek on the north. A narrow belt of them is apparently exposed round the north side of the intrusive mass of Glacier Mountain. The approximate northern boundary of the main area extends southeast of Glacier Mountain and crosses the boundary at a point which is probably not far north of Fortymile Dome.

An attempt to separate the complex into distinct formations is not justified by the facts at present available. The uppermost part is apparently carbonaceous schist with interbedded quartzite, also in part carbonaceous, and crystalline limestone. From these beds there is apparently a gradual metamorphic transition, with repeated alternation of beds originally different in composition, to more and more crystalline rocks and to rocks that have undergone an increasing amount of intrusion, and the base of the formation is probably most thoroughly magmatized.

DEVONIAN.

Green and black phyllites and cherty slates, cherts, greenstones, serpentine, quartzites, and limestones, all regarded for the most part of Devonian age, characterize a large part of the northern half of the quadrangle. It is possible that Silurian or Carboniferous rocks are included in this grouping, but at present there is no evidence for their separation. They form the bluff just below Eagle, the bluffs above Eagle on the north side of the river, and are abundant below Eagle along the Yukon, where they are in close relation with Carboniferous rocks. In the southwestern part of the quadrangle they occur on the Fortymile from the mouth of Dennison Fork to a point about 2 miles above Franklin Creek. The drainage area of Chicken Creek is formed partly of these rocks. A belt of them is present also in the area about the headwaters of King Solomon and Champion creeks. This belt apparently terminates to the southeast, and to the northwest probably connects with a considerable body of these rocks that lies outside of the quadrangle. There is also a small area of them on Canyon Creek.

The lithologic character varies greatly. The greenstones and next to them the limestones are the prominent members of this group. This formation offers a strong contrast to the preceding rocks by an

absence of the intense metamorphism generally characteristic of the latter. In the sedimentary part of the formation the characteristics of sedimentary rocks still prevail and the limestones in places still retain fossil evidences of animal life. At two localities, one at Thirteenmile camp southeast of Eagle, and one on the Fortymile just below the mouth of Napoleon Creek, the writer found fragments of crinoid stems in the limestones, but these are of little value for stratigraphic purposes. The limestones are in places thin bedded, bluish, and occur interbedded with shaly phyllites; at other localities there are massive beds up to 150 feet or more in thickness.

The contemporary igneous material so characteristic of this formation is predominantly of a diabasic or basaltic character and much of it is tuffaceous. The relation of these rocks to the limestones is well shown in the ridge that extends east and west along the north side of Mission and Excelsior creeks. Here a gray limestone about 150 feet thick is capped by a very fine-grained green vesicular basaltic rock. Black shaly slates are associated with the limestone in this same ridge at a locality near Eagle, and the green rock forms the capping, as at the other locality. Besides the igneous material interbedded with the sediments there are dikes of diabasic character. The Devonian rocks have been closely folded, but otherwise have suffered little alteration.

The succession of rocks assigned to the Devonian is not completely exposed at any locality observed in the Fortymile quadrangle. A partial section is shown in the ridge extending northeast from Glacier Mountain, between the headwaters of Excelsior Creek and Seward Creek. The intrusive mass of Glacier Mountain is bordered by quartzite schist assigned to the pre-Ordovician. The succeeding rocks are fairly well exposed for about a mile. The attitude over a part of this distance is nearly vertical. The base of the Paleozoic rocks is taken to be a band of carbonaceous phyllites outcropping over a width of about 500 feet. These are followed in order by an outcrop of massive limestone about 600 feet wide, a massive quartzite 50 feet thick, black and gray slaty phyllites outcropping at intervals over about half a mile, and then meager outcrops of more limestone. A mile farther along the ridge are greenish slates, and 2 miles from them, beyond an area about three-quarters of a mile wide of loosely consolidated conglomerate and sandstone assigned to the Tertiary, are outcrops of greenstone. Shales and slates, which carry a few Devonian fossils, occur at several localities below Eagle on the Yukon. These beds, which aggregate about 1,000 feet in thickness, represent the uppermost member of the Devonian, and are succeeded conformably by the lowest member of the Carboniferous. As this formation was not definitely recognized in other parts of the quadrangle, the rocks are here grouped with the other Devonian terranes, though they probably represent a horizon higher in the geologic column.

CARBONIFEROUS.

The Carboniferous is represented within the limits of the quadrangle by two formations, the Calico Bluff and the Nation River. These formations are present below Eagle on the Yukon and have been studied by Brooks and Kindle,[a] from whose description the following paragraphs are quoted:

The lower of the two well-defined formations, for which the name "Calico Bluff" is proposed, embraces about 900 feet of black and gray shales, with some slate, and numerous interpolated thin beds of limestone. The whole formation carries an abundant fauna, assigned to the Mississippian by Dr. George H. Girty. Its typical exposure is at Calico Bluff on the Yukon, about 15 miles below Eagle. The Calico Bluff formation is separated by an unconformity from the succeeding formation, here called the "Nation River." There can be little doubt of this unconformable relation, though no complete section was found showing both. The relations are inferred from the apparently abrupt change in character of sediments to fine limestone from coarse fragmental material. It is not improbable, however, that detailed mapping may reveal a considerable thickness of strata lying between the Calico Bluff and Nation River, as here described. Whether such strata, if found, should be included in one or the other of these formations, or be mapped as a distinct stratigraphic unit, must be left to the future to determine.

* * * The physical changes involved in the transition from Devonian to Carboniferous sedimentation embraced a continuation of the deposition of shale-producing sediments, interrupted at intervals by periods of limestone deposition. The Carboniferous fauna seems to have made its first appearance in the region with the advent of limestone-forming conditions during the temporary cessation of the deposition of black-shale sediments. The regular and frequent alternations of closely folded light-colored limestone and dark shale which characterize the Carboniferous portion of the nearly vertical face of Calico Bluff give it an unusual and striking appearance, as seen from the river.

The Carboniferous fossils obtained here were submitted to Dr. George H. Girty, who reports the following species from bed 9j, * * * the lowest bed holding Carboniferous fossils:

Fossils from bed 9j, Calico Bluff.

Fenestella sp.
Polypora sp.
Cystodictya sp.
Stenopora? sp.
Rhombopora sp.
Derbya? sp.
Chonetes aff. choctawensis Girty.
Productus aff. cherokeensis Drake.
Productus aff. inflatus McChesney.
Productus aff.? hirsutiformis Walcott.
Productus aff. punctatus Martin.
Productus aff. setigera Hall.
Productus aff. biseriatus Hall.
Productus sp.
Spirifer aff. bisulcatus Sowerby.
Spirifer aff. keokuk Hall.
Spirifer sp.
Reticularia aff. setigera Hall.
Martinia? sp.
Leiorhynchus sp.
Aviculipecten sp.
Myalina sp.
Macrodon aff. carbonarius Cox.
Bellerophon sp.
Phillipsia sp.

[a] Brooks, Alfred H., and Kindle, E. M., The Paleozoic and associated rocks of the Upper Yukon: Bull. Geol. Soc. America, vol. 19, 1908, pp. 255–314.

From the black shale above this fauna * * * a small fauna was secured containing three species, reported by Girty as follows:

Liorhynchus aff. mesicostale Hall.
Goniatites undet.
Orthoceras sp.

The *Liorhynchus* of this fauna is a recurrence of the species * * * which is referred to the Devonian. It is characteristic of some of the species of this genus in the New York Devonian to be associated with black shales at various horizons in a section, while they are entirely absent from the intervening sediments.

The following species have been recognized from the several beds from j to n of the Calico Bluff section, by Doctor Girty, which were not included in the fauna of division j:

Fossils from beds 9j to 9n, Calico Bluff.

Zaphrentis sp.
Archæocidaris sp.
Fenestella sp.
Pinnatopora sp.
Polypora sp.
Rhombopora sp.
Cystodictya sp.
Stenopora sp.
Stenopora? sp.
Schizophoria sp.
Chonetes sp.
Chonetes aff. choctawensis Girty.
Productus aff. biseriatus Hall.
Productus aff. semireticulatus Martin.
Productus aff. hirsuitiformis Walcott.
Productus aff. parvus Meek and Worthen.
Productus aff. cherokeensis Drake.
Productus aff. cora D'Orbigny.
Productus, 2 sp.
Spirifer aff. bisulcatus Sowerby.
Spirifer aff. keokuk Hall.
Reticularia aff. setigera Hall.
Ambocœlia? sp.
Camarotœchia? sp.
Camarophoria sp.
Aviculipecten sp.
Macrodon n. sp.
Pleorophorus aff. subcostatus Meek and Worthen.
Pleorophorus sp.
Chiton sp.
Trachydomia? sp.
Pleurotomaria, 3 sp.

Doctor Girty makes the following statements regarding the horizon represented by the Carboniferous of Calico Bluff and other sections representing a similar horizon:

"I have been unable to trace the affinity of this fauna with a member of the Russian section, but presumably it is somewhere near the age of the *Productus giganteus* zone, in which case a gap of considerable extent separates this from the Upper Carboniferous fauna described below. The fauna of the Calico Bluff section appears to be related to that of the upper part of the Mississippian section as developed to the south and west of the typical area. I refer to the "Spring Creek" limestone and Marshall [should read Moorefield—G. H. G.] shale of Arkansas and the Caney shale of Indian Territory (and probably the Eureka [should read White Pine—G. H. G.] shale of Nevada), which from available data appear to represent the upper portion of the typical Mississippian section. This relationship of the Alaskan fauna I believe to be a real and not a fancied one, and while belonging distinctly with the faunas just mentioned, rather than with the typical Osage and Kinderhook, it would at present be unsafe to say that these localities represent the upper Mississippian alone."

Since the preceding observations of Doctor Girty indicate that the nearest faunal equivalents of the Calico Bluff fauna in the United States are repre-

sentatives of the upper portion of the Mississippian section, it should be pointed out that all of the available stratigraphic evidence indicates that it is the earliest Carboniferous fauna present in the Yukon section. The stratigraphic evidence appears to place it somewhat lower than the faunal evidence and to indicate that it represents both the upper and lower portions of the Mississippian section.

A section about 2 miles above the mouth of Seventymile River, on the opposite bank of the Yukon, exposes the Carboniferous series seen at Calico Bluff and some higher beds which show the Lower Carboniferous shales terminated by a coarse conglomerate which, with some interbedded shales, is about 200 feet thick. This conglomerate may represent the base of the Nation River series. The limestones and shales here show about the same association of species as in the Calico Bluff section.

The Nation River series includes about 3,700 feet of gray clay shales with some clay slates interpolated with heavy beds of conglomerate and some sandstone. It is typically exposed along Nation River, where it includes some small seams of bituminous coal. The limits of this formation are well defined. The base is believed to be marked by an unconformity which separates it from the shales and limestone of the Calico Bluff formation. At the top it is limited by the heavy limestone which previously formed the topmost member of the Carboniferous and will be described below.

Two conglomerate beds are particularly striking in this formation. One occurs at the base and is very massive, and the second, which is not quite as heavy, occurs about 1,000 feet above the base. The succeeding thousand feet is largely made up of shales, with some fine conglomerates and sandstone, while the upper 500 feet of the formation is chiefly gray shales. Some bituminous coal beds occur in the lower part of the section.

The Nation River formation has yielded no fossils except a few plant fragments, upon which Mr. David White has reported as follows:

"This collection consists of three fragments of rock with one counterpart containing small fragments of carbonized wood, decorticated stems, etc. The plant remains bear evidence of transportation, maceration, and trituration, the result being that none of them are definitely determinable, even generically. One fragment, about 1 cm. in length and 6 mm. in width, evidently represents a branch of some lepidophyte or gymnosperm. Although it is partially decorticated as the result of maceration, so that the epidermal characters are lost, the subepidermal features of this branch so closely resemble those of certain Carboniferous strobiliar axes and earlier types of phyllotaxy that I am inclined to regard it as probably belonging to one of these Paleozoic forms. In fact, though constrained to emphasize the poor condition and limited characters presented by the specimen and the consequent hazard of any attempt at identification, I am nevertheless disposed to regard this fragment as belonging to one of the Carboniferous lepidophytes. Among the latter it bears the closest resemblance to some of the early forms in the basal Carboniferous, or the late Devonian."

The stratigraphy and the invertebrate faunas of the associated formations strongly support the opinion that the Nation River coal is of Carboniferous age. The coal seam occurs near the axis of an anticline, the beds dipping away in opposite directions at angles of 30° to 60° on the north and south sides of the Nation River Valley. South of the river they pass under a massive white limestone, carrying an Upper Carboniferous fauna, and in which a series of open folds is developed along the north side of the Yukon. Considerable interest attaches to the beds at the Nation River coal mine because it is the only locality in the Yukon Basin where beds of Carboniferous age have afforded coal.

TERTIARY.

The rocks regarded as Tertiary include sandstone, clay, lignite, shale, and conglomerate. The state of consolidation varies greatly at different localities, but the plant remains, which are in many places very abundant in these deposits, have been referred, so far as they were determinable, to the Kenai formation, of Eocene age. The most extensive body of these deposits is in the valley of the Seventymile, where a well-defined belt of them extends northwestward toward the Birch Creek region. To the southeast a portion of this belt forms the lower hills south from Eagle and extends still farther southeastward to Yukon River.

Northward from the areas of Paleozoic rocks that form the hills around the headwaters of American and Wolf creeks there are found, in the valleys of these streams and in the ridge between them, brownish sandstone, clay, lignite, ferruginous nodules with plant remains, and loosely consolidated conglomerate. These rocks were observed about 4 miles above the mouth of Wolf Creek in the valley of a small tributary from the west. Farther north, on Wolf Creek, about 1½ miles above the mouth, a bluff of conglomerate 125 feet high forms the west side of the valley. The conglomerate is composed essentially of black and red chert pebbles and vein quartz, with a few pieces of granite and diorite. The conglomerate in places grades into a brownish sandstone. On the west side of Mission Creek, about 2 miles above Excelsior Creek, there is a bluff 150 feet high of similar conglomerate. Brownish sandstone is associated with it and there are ferruginous nodules with plant remains. The rocks at this locality dip northwest about 50°.

Still farther to the north, in the lower part of the valley of Bryant Creek, there is an almost continuous section of these rocks nearly a mile wide. About 4 miles above the mouth of Bryant Creek are thin-bedded gray and black shales, grits, and conglomerate. In the shales are numerous heavy, yellow, ferruginous nodules containing plant remains, which are also abundant in the thin-bedded grits. The strike is about N. 70° E. and the dip 15° N. About 700 feet downstream are precipitous slopes of conglomerate with an east-west strike and a nearly vertical dip. These beds, with possibly some shales, occur over a width of about 3,000 feet, and are succeeded by 60 feet of dark and gray paper shales and grit with the same strike and dip and in close contact with conglomerate on both sides. The shales contain many plant remains, and the sandy beds of the conglomerate next to them exhibit irregular impressions a foot or more long and up to 4 inches wide. These show generally well-defined linear markings, and there seems little doubt that they represent some form of vegetable life. The shales are succeeded by 350 feet of con-

glomerate, and this by more fine sediments, 50 feet thick, composed of gray, micaceous, somewhat loosely consolidated, leaf-bearing shales and grits and fine-grained compact shales, in which leaves have been very perfectly preserved. These shale beds, like the others, are in contact on both sides with conglomerate. That on the downstream side outcrops, with possibly some interbedded shales, for nearly a quarter of a mile, to a point where a wooded slope descends gradually toward the Seventymile. Precipitous slopes were seen nearly 2 miles to the north, across Seventymile. These were not visited, but the continuation of these slopes a few miles to the west is composed also of conglomerate. The maximum size of pebbles observed in the conglomerate was 5 inches; the average was from 1 to 3 inches. The material is mostly black, gray, and green chert, quartzite, and vein quartz. The rock grades into a sandstone with a cement resembling mortar. All the way to Barney Creek the ridge on the north side of the river is made up of this formation, either nearly vertical or dipping steeply toward the valley. The cement contains much ferruginous matter, and the rock breaks down easily into its constituent materials, which form loose heaps of gravel and sand. The spurs on the south of Seventymile are also of this material as far as the falls. The steepness of the dip is well shown in the nearly vertical position of the leaves so abundant in the shale.

In the Chicken Creek area patches of sandstone with associated shale, clay, and lignitic coal occur. There are ferruginous nodules containing fragments of dicotyledonous leaves, and there are also badly preserved plant remains in the shales and sandstones. So far as these are determinable they indicate the relationship of these beds with the Kenai, to which they are provisionally referred.

On Napoleon Creek and on the Fortymile at the mouth of Walker Fork there are breccias, conglomerates, sandstones, and coal-bearing beds similar to those of Chicken Creek. The unconformable contact of this formation with underlying Paleozoic rocks is well exhibited on the east side of the Fortymile about 900 feet above the mouth of Walker Fork. The older formation is composed of gray, green, and black phyllites with some cherty beds. The overlying formation commences with a breccia about 15 feet thick, composed of fragments up to 4 inches or more in diameter of the underlying greenish phyllites, cemented with a ferruginous sandy matrix. This is overlain by about 4 feet of fine-grained bluish argillaceous beds, the material of which breaks with a conchoidal fracture. Overlying this fine material is about 20 feet more of breccia, followed by alternating beds of shale and massive conglomerate. The shales carry abundant poorly preserved plant remains, but unfortunately none were found sufficiently well preserved to admit of determination. These rocks are tilted and

exhibit dips up to 40°. In the absence of evidence to the contrary they are correlated with the other occurrences and regarded as Kenai.

A deposit on the west side of Mission Creek about a quarter of a mile above the mouth of Excelsior Creek is unlike those above described. The bluff, about 90 feet high, is composed mostly of very slightly consolidated angular material consisting largely of granite. There are fragments of coarsely porphyritic light-colored granite 2 feet or more in diameter, also much fine material of the same kind and a few waterworn pebbles, but apparently no chert pebbles, which are so characteristic of the other deposits. There are some thin beds of gray sandstone and clay with carbonaceous matter. This deposit is about 1½ miles below the locality on Mission Creek where conglomerate associated with rocks containing characteristic Kenai fossils occurs. It is regarded provisionally as Kenai.

A conglomerate of doubtful age occurs on Moose Creek just at the eastern edge of the quadrangle. It is strikingly coarse, containing bowlders up to 6 feet or more in length. The rocks composing it are principally schist, but there is also a small proportion of limestone. One bowlder of limestone was observed, the exposed portion of which measured 6 by 15 inches. Vein quartz pebbles are fairly abundant. The cement is composed for the most part of coarse sand, but in some places fine sand occurs in limited quantities between the bowlders. In the vicinity of the limestone that forms the hill east of the Fortymile and north of Moose Creek the deposit is finer and the constituents are more angular.

No evidence of the stratigraphic position of this conglomerate was observed. Its state of consolidation is similar to that of the other deposits, and it probably does not differ greatly in age from them. Provisionally it is included with them.

Lithologically there is much difference between the elements included above in the Kenai, and there is also much difference in the degree of consolidation, even within narrow limits in the same outcrop. All the paleontologic evidence at present available precludes a separation into distinct formations. It may be stated that in general the lower portion of these deposits seems to be characterized by the presence of finer material and that the uppermost portions are conglomeratic. The clays, sandstones, and lignites are, wherever observed, close to the underlying older rocks. The thickness of these deposits in the Fortymile quadrangle is probably greatest in the valley of the Seventymile, where it reaches perhaps 3,000 feet or more. The beds have been closely folded in the Seventymile Valley and reduplication is possible. The formation has probably originated from lacustrine conditions giving place later to fluviatile conditions.

Following is a report by F. H. Knowlton on the material collected by the writer during 1903 from the rocks assigned to the Kenai:

3AP 224. Irene Gulch, Chicken Creek: Fragments of stems, indeterminable.

3AP 224½. McDowell claim, Chicken Creek: *Equisetum* sp.

3AP 237. Mouth of creek, 1 mile west of Chicken: Black carbonaceous shale with minute plant fragments, indeterminable.

3AP 251. Chicken Creek: Fragments of dicotyledons, possibly *Corylus MacQuarrii*, but uncertain.

3AP 330. Wolf Creek: *Taxodium dubium?* Heer; *Populus* sp.

3AP 336. Branch of Wolf Creek: *Populus*, cf. *P. Richardsoni* Heer; dicotyledonous fragments.

3AP 337. Branch of Wolf Creek: Only fragments of stems and bark.

3AP 348. Bryant Creek: *Sequoia Langsdorfii* (Brgt.) Heer; *Taxodium dubium?* Heer; *Populus arctica?* Heer; *Populus Richardsoni?* Heer; *Corylus MacQuarrii* (Forbes) Heer; *Quercus platania* Heer; *Betula prisca?* Ett.

3AP 349. Bryant Creek: *Sequoia Langsdorfii* (Brgt.) Heer; *Corylus MacQuarrii* (Forbes) Heer; *Populus arctica* Heer; *Populus Richardsoni?* Heer; *Juglans nigella?* Heer.

3AP 350. Bryant Creek: *Sequoia Langsdorfii* (Brgt.) Heer; *Equisetum* sp.; *Populus latior* Heer; *Populus Hookeri* Heer; *Fagus Deucalionis* Unger; *Quercus furcinervis* (Ross M.) Unger; *Juglans* sp.?

3AP 355. Mogul Creek: *Sequoia brevifolia?* Heer; *Corylus MacQuarrii* (Forbes) Heer; *Populus* sp.?

3AP 432. Mission Creek, 2 miles above junction with Excelsior: *Corylus MacQuarrii* (Forbes) Heer; *Betula prisca* Ett.; *Fagus Deucalionis* Unger.

Listing the species from all the localities, we have the following:

Sequoia Langsdorfii.
Sequoia brevifolia.
Taxodium dubium.
Populus arctica.
Populus latior.
Populus Richardsoni.
Populus Hookeri.
Corylus MacQuarrii.
Quercus furcinervis.
Quercus platania.
Fagus Deucalionis.
Betula prisca.
Juglans nigella.

Taking well into account the fact that not all of the above species are determined with absolute certainty, it is nevertheless perfectly clear that all are of the same age, and I do not hesitate to say that this is Arctic Miocene.[a] Not a trace of the Cretaceous element appears.

ALLUVIAL DEPOSITS.

The alluvial deposits include the bench gravels that are common on so many of the benches throughout the area and the deposits of the present streams. The deposits of the higher benches are sharply differentiated from those of the present streams; those of some of the lower benches merge into the present stream deposits. There is no definite evidence in the area as to the age of the higher bench

[a] This flora was first described as the Arctic Miocene. Subsequent investigations have shown that it is of Eocene age, but the old name is still retained.—L. M. P.

gravels, but they are correlated with the high gravels in other parts of the Yukon-Tanana region and referred to the Pleistocene.

The high bench of the Fortymile is very marked and is sufficiently distinctive to lend itself to topographic expression, even on the scale of the map of the Fortymile quadrangle. It is especially well developed between Steele Creek and the mouth of Canyon Creek on the north side of the river, and at a level of about 300 feet above the stream, on this bench, gravels are found that are reported to be auriferous. Nugget Gulch cuts this bench. Most of the pay gravel found in Nugget Gulch is reported to have been in that portion of the valley that cuts the high bench, and is due perhaps to reconcentration from the latter. Gravels about 200 feet above the Fortymile were observed near Bonanza Bar. The high gravels of Lost Chicken Creek, described elsewhere in this report, proved to be richly auriferous. There are extensive deposits of gravels in the Mosquito Fork Valley at a height of about 300 feet above the stream. On Mission Creek 20 feet of stream gravels were observed forming the capping of a bluff 70 feet high. There is another bench in the Mission Creek valley at a height of 15 to 20 feet above the stream, and a bench of similar height has extensive development in the valley of the Seventymile, where it is distinctly differentiated from the gravels of the present stream. No detailed studies of the material or distribution of these various bench deposits have been made, but so far as observed they are composed of material of fluviatile origin and are all definitely related to the valleys in which they occur.

The stream gravels have been derived from the bed rock within the valleys of the streams along which they occur, or from the older gravels present on the benches, or from conglomerates composed of fluviatile material, and betray no evidence of other than a fluviatile origin. They are described in relation to the gold occurrences.

Silts have been abundantly deposited in the valley of the Yukon at different levels down to that of the present flood plains. These were probably laid down under lacustrine conditions and under the interaction of lacustrine and fluviatile conditions, and date probably from the Pleistocene to the present time.

It has been impossible to differentiate these deposits upon the map. The areas covered by the deposits of the present streams are roughly delimited, and it may be accepted as a general fact that in nearly every valley there are deposits, more or less extensive, of bench gravels.

STRUCTURE.

An examination of the map (Pl. IV, in pocket) will show that the major structures of the pre-Carboniferous rocks trend in a northwesterly direction. Thus they are parallel with the dominant tectonic features of this part of Alaska. As has been stated, the pre-

Ordovician rocks are very intricately folded, with great complexity of dips.

The Devonian beds are somewhat less deformed, but their structure, too, owing to scarcity of outcrops in some areas and to lack of detailed mapping, can not be expressed in general terms. For this reason it has not seemed worth while to record graphically by means of a cross section an interpretation of the structure, which could be regarded as little more than a bold guess. From the evidence in hand it is perhaps fair to assume that the Devonian areas, as indicated on the map, mark synclinoria caught up in a highly deformed complex of metamorphic sediments and igneous rocks.

The strike of the Carboniferous rocks is at variance with that of the older terranes, being northeasterly. They occur as a series of broad, open folds, the best example of which in this quadrangle is the anticline shown in cross section along the river between Eagle and the mouth of Seventymile. Here the two Carboniferous formations are exposed in the limbs of the anticline, while the Devonian occurs along the axis of the fold. One nose of the anticline is exposed at Calico Bluff.

The Tertiary beds are but slightly deformed, though in places they exhibit vertical dips. The axis of deformation of the Tertiary terranes parallels that of the pre-Carboniferous terranes. This is probably connected with the form of their deposition in basins or valleys which were carved out of the older terranes.

IGNEOUS ROCKS.

There is a large variety of intrusive igneous rocks in the Yukon-Tanana region, and these were fully described by Spurr.[a] Those that have been derived from the granito-dioritic magma are especially common. While extrusives of similar composition occur at short distances outside of the quadrangle, the extrusives within the quadrangle, so far as observed, are chiefly diabasic and basaltic and are confined to occurrences contemporaneous with the Paleozoic rocks, in which they are so abundantly interbedded as to have impressed their characteristics upon a large part of the entire group.

The intrusive rocks range in composition from persilicic rocks, composed almost entirely of quartz and feldspar, to rocks composed predominantly of hornblende or of augite. They occur as large intrusive masses, like Glacier Mountain and the large area that extends into the Fortymile quadrangle from the southwest and also as innumerable dikes and sills. Besides the variation in composition and in mode of occurrence there has been a variation in time of intrusion. Most of the intrusive masses are comparatively fresh, but some of them were

[a] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rep. U. S. Geol. Survey, pt. 3, 1898, pp. 224–249.

intruded early enough to undergo metamorphism along with the schists, and these present themselves now as gneisses of varying composition.

The persilicic rocks, termed alaskite by Spurr, occur as dikes or sills from many feet to a fraction of an inch in thickness. They are light in color, in some cases white, so that at a distance they simulate outcrops of limestone. They are composed essentially of quartz and feldspar with a little mica. The feldspar is orthoclase, albite, oligoclase, and in some cases mainly andesine with some microcline. The constituents are xenomorphic and range up to 3 millimeters or more in diameter. Cataclastic phenomena are general and exhibit themselves macroscopically as crumpling or as separation of the dike or sill into lenticular fragments, and under the microscope as bent twinning lamellæ in the feldspars, as comminuted marginal areas of the grains, or as fracturing of the grains, feldspar grains being frequently crushed into several fragments which have been cemented by a deposit of quartz. Sericite is sometimes present to a limited amount between the grains of quartz and feldspar, and many of the feldspar grains are sprinkled with it. Where good exposures of the schists intruded by these acidic dikes are shown it is possible to observe the transition of these rocks to quartz veins through disappearance of the feldspar.

Biotite granite has a darker color, due to the presence of the biotite. There are areas of considerable extent outside the quadrangle, but within the quadrangle it occurs commonly as rather small dikes and sills in the schists. The rock is generally even grained, but in some localities has a porphyritic development with individuals of alkali feldspar an inch or more in diameter. Most of the augen gneisses in the Yukon-Tanana region are referable to old intrusions of this kind of rock that have been metamorphosed along with the schists into which they were intruded.

A hornblende granite composed of quartz, alkali feldspar, abundant soda-lime feldspar, hornblende, some biotite, and titanite is rather commonly distributed. The alkali feldspars frequently show porphyritic development. Cataclastic phenomena are common.

The large intrusive mass forming Glacier Mountain and adjacent areas, so far as can be judged from material collected at several peripheral points, and from alluvial material derived from the mountain, is composed predominantly of a rock referable for the most part to quartz diorite. In most of the material examined the proportion of soda-lime feldspar is very abundant, the automorphic individuals of this mineral are in immediate contact with quartz grains, and the proportion of interstitial alkali feldspar is small. There are porphyritic dikes of this rock cutting the more evenly granular variety, and the prominent point at the head of Bear Creek is composed of this rock. In the schists surrounding the main body are numerous dikes, and

some of these are more basic, containing a large proportion of hornblende and approaching diorite in composition.

The large area of intrusives in the southwestern part of the quadrangle, forming the bed rock along Dennison Fork and a large part of the bed rock in the Chicken Creek area, is composed of the same kind of rock. This rock is porphyritic in places and is also cut by finer-grained porphyritic dikes of the same general composition. This rock also, like the granites, has its gneissoid representatives, older bodies of approximately the same composition having intruded the schists. Hornblende-plagioclase gneisses along the Fortymile are referable to this origin. Some of these are thoroughly recrystallized; others, presumably those intruded nearer the surface, exhibit different stages of reduction to gneisses by cataclastic action combined with some recrystallization. The occurrence of gold on Mosquito Fork is in a brecciated mineralized zone of this rock. Along Dennison Fork it is cut occasionally by felsitic dikes and dikes of basalt.

Dioritic marginal facies of the rocks above described and dioritic dikes occur to some extent. Dikes are found composed almost entirely of hornblende and biotite with a little plagioclase and quartz. But in general dioritic rocks are not so common as those of a more intermediate type.

A massive dike of pyroxenite occurs about 1½ miles below the mouth of Canyon Creek. The rock is composed predominantly of xenomorphic augite with some biotite and hornblende, titanite, and iron mineral. Some of it is coarse, with glistening biotite plates an inch or more in diameter that attract attention to the blackish outcrop of this rock. The rock in contact with it is quartzite schist. The dike is cut by some persilicic dikes. Another dike of similar composition was observed on the Fortymile just below the mouth of Discovery Fork.

The schists and the intrusives above described are cut by a few fresh basaltic dikes. Dikes of this rock have been observed on Wade Creek, Walker Fork, and Dennison Fork. The dike on Walker Fork is composed of pinkish augite, basic soda-lime feldspar, and olivine. A noteworthy constituent is a quartz inclusion, corroded, fractured, surrounded by a zone of augite, and entirely surrounding augite, which has crystallized from the magma in a corroded cavity of the quartz.

There is a considerable area of this olivine basalt in the Chicken Creek area. Part of it at least is probably intrusive, like the dike of the same material in the quartz diorite of Dennison Fork. Part of it, however, may be in the form of a flow. The rock on Myers Fork is composed of basic soda-lime feldspar, occasional large augites, abundant blades of iron mineral, and brownish-black undifferentiated material; amygdaloidal cavities are numerous.

The diabasic and basaltic material contemporaneous with the Paleozoic rocks comprises both intrusives and extrusives. The extrusives have been accompanied by more or less tuffaceous matter. These rocks have all been more or less altered and are composed at the present time largely of chloritic, uralitic, and serpentinous material.

The intrusion at different periods of so large a quantity of igneous material and the thorough manner in which much of this has become mingled with the rocks of sedimentary origin indicate conditions favorable for mutual influence. That the unaltered intrusions of quartz diorite have brought about contact metamorphism in the intruded rocks is shown by the andalusite contact zone about the intrusive mass that is situated just off the southwestern border of the quadrangle, at the head of Buckskin Creek.

The age of the latest intrusions of granular rocks has not been determined, but the Paleozoic rocks are penetrated by them. The intrusions like that of Glacier Mountain and that of Dennison Fork and Chicken Creek are similar in composition and occurrence to rocks of the Rampart region that have intruded Upper Cretaceous sediments. The end of the Mesozoic was a time of extensive intrusion, and it is probable that some of the rocks of intermediate composition in the Fortymile quadrangle were intruded at that time. The age of the fresh basaltic rocks is also indefinite. There are areas of fresh volcanics outside the limits of the quadrangle; some of these are probably at least post-Kenai in age, and the degree of freshness of some of them would indicate a comparatively recent origin.

ORIGIN OF THE GOLD.

There are a few localities in the Fortymile region where gold has been found in the bed rock, and these are described in detail in the following section of this report. One of these localities is on Mosquito Fork, about 2½ miles west of Chicken Creek. The gold at this locality occurs in a brecciated zone of quartz diorite that has undergone silicification and mineralization. Another locality is near the head of Chicken Creek, where gold is found in thin calcite seams in black phyllites in close proximity to about the same kind of rock as that on Mosquito Fork. The placers of Chicken Creek have probably derived a part at least of their gold from this source. A locality on the ridge south of Kalamazoo Creek contains gold in brecciated vein quartz in quartzite schists within the zone of abundant intrusions. The alluvial deposits of the streams have been derived from the bed rock of the valleys in which they occur, and there has been no interference by glaciation in this area with the orderly deposition of material by stream action. The bed rock in some of these valleys, especially those of the Fortymile region, is composed of schists of

sedimentary origin containing many small quartz veins. Gold has been found in such small veins on Davis Creek, and on many creeks nuggets occur with quartz attached. It is probable that a large part of the gold of the Fortymile area has been derived from this source. The gold of the Eagle area is derived apparently from mineralized areas or quartz veins in bed rock that is composed of carbonaceous phyllites, limestone, and greenstone of Paleozoic age. The origin of the gold in the Seventymile area is not clear, as there are too many possible modes of origin. It has probably been concentrated to the present stream gravels from bench gravels that were derived partly from the conglomerates in which the streams are cut and partly from other sources. The placers of Woodchopper Creek are in conglomerates of the same age as those of the Seventymile and occur in the extension of the same belt to the west. They are believed by Brooks[a] to have originated from the conglomerate, where the gold had been deposited as alluvial gold contemporaneously with the constituents of the conglomerate.

Some of the minerals found associated with gold in the Fortymile quadrangle are barite, galena, native lead, argentite (silver sulphide), cinnabar (mercury sulphide), iron pyrites, hematite, limonite, magnetite, rutile, and garnet.

GEOLOGIC HISTORY.[b]

In spite of the absence of detailed information, it will be well to outline some of the salient features of the geologic history of this area.

That the oldest sediments, including arenaceous, argillaceous, and calcareous material, were deposited in a pre-Ordovician sea seems probable, but no more definite assignment of the period when this deposition took place can be made. What is known of the geology of the adjacent regions makes it probable that this sea was of wide extent. Accumulation of sediments went on until a great but unknown thickness, probably to be measured in thousands of feet, was laid down, intrusions took place, and then, some time before the middle Devonian, an extensive crustal movement, which brought about a metamorphism of the entire mass, took place. Limestones recrystallized, sandstones changed to quartzites, and slates to phyllites and schists.

This disturbance was probably followed by erosion, of which, however, no records have been discovered in this quadrangle. In any event, possibly during Silurian and certainly during Devonian time, sedimentation was again in progress in this field. Sedimenta-

[a] Brooks, Alfred H., Bull. U. S. Geol. Survey No. 314, 1907, p. 199.

[b] This section was prepared in cooperation with Alfred H. Brooks.

tion during the latter period was accompanied by volcanic outbursts, which contributed the greenstones and tuffs so intimately associated with some of the Devonian terranes. The sediments deposited during Devonian time were not unlike those laid down during the preceding epochs. In late Devonian time the deposition of at least a thousand feet of argillaceous material in the northeastern part of the quadrangle took place. This material, now found as slate, which could not be differentiated from the older Devonian rocks in other parts of the quadrangle, belongs distinctly to the upper part of the system and may very likely be separated from the older terranes by an interval of erosion. Tectonically this uppermost Devonian member is to be grouped with the Carboniferous horizons, from which it is not separated by an erosional interval.

Carboniferous time began with an increase in calcareous matter and the appearance of a new fauna. Deposition of calcareous and argillaceous material continued until at least a thousand feet of strata had accumulated, called the Calico Bluff formation. It is probable that there was then a crustal movement which left a land mass exposed and inaugurated a period of erosion. In any event, the basal beds of the next series of sediments (Nation River formation) are made of coarse fragmental material, indicating a near-by land mass and probably an unconformity. The evidence therefore points to the conclusion that the oldest Carboniferous (Calico Bluff formation) was eroded before the deposition of the second member of the Carboniferous (Nation River). Sedimentation continued until at least 4,000 feet of arenaceous and argillaceous material was deposited. In adjacent areas, though not within the Fortymile quadrangle, there is evidence of another epoch of erosion following the deposition of the Nation River. This erosional interval was succeeded by deep-sea conditions, which continued throughout the latter part of Carboniferous and into Triassic time. There is no depositional record of the Mesozoic within the quadrangle, but the Lower Cretaceous sea probably covered it. The close of Lower Cretaceous time marked a period of mountain building and intrusion throughout most of Alaska, and some of the granitic rocks of the Fortymile quadrangle were probably intruded at this time.

Deposition during Tertiary time is represented by the fresh-water plant-bearing beds, here assigned to the lower Eocene. These were in part fluviatile, in part lacustrine, and probably never mantled any considerable part of the region. Their distribution indicates deposition in an extensive drainage system, possibly partly broken by lakes.

The later history of the province is a complex one which has not yet been fully deciphered. There was at least one extensive period of erosion, when much of the area was reduced to a peneplain. It

does not now seem likely that all the flat-topped topographic features can be assigned to this one period of erosion, as has been previously supposed, but the correlation and genesis of these varied topographic features must await further studies. The topographic records, such as flat-topped ridges, spurs, and well-marked stream benches, point to intermittent uplift since the first widespread period of erosion of which there is evidence in the even crest lines of the higher interstream areas. Glaciation has played no part in molding the topographic forms within the quadrangle, which lies entirely outside the glaciated area.

GOLD PLACERS.

DISTRIBUTION.

The material concerning the placers is presented in the order of their areal distribution, and is followed by an account of mining methods and statistics of production.

The localities of productive placers are indicated on the geologic map (Pl. V, in pocket). It is not practicable to show the distribution of the auriferous gravels, because nearly all the alluvium carries at least a trace of gold, and prospecting has not gone far enough to disclose how much of it may carry workable placers. The area of the Fortymile and its tributaries contains the most localities and the widest distribution of gold known to be in quantities sufficient to be mined. The map shows that this distribution of gold corresponds with that of the pre-Ordovician metamorphic rocks and associated intrusives. These are the rocks that have proved most productive of placer gold in the Birch Creek and Fairbanks regions, and merit, wherever they occur, attention on the part of the prospector. They are not everywhere auriferous, but it is in association with them especially that placer areas are likely to be found. The occurrence on creeks in the vicinity of Eagle in Paleozoic rocks is more local, being limited thus far to small areas on American Creek and its tributary, Discovery Fork. The Seventymile area includes occurrences at several rather widely separated localities in a region where the bed rock is predominantly formed of Tertiary conglomerates. This suggests that the gold of Seventymile is a secondary concentration from Tertiary placers. It does not follow, however, that the gold in the Tertiary beds is sufficient to pay for the cost of extraction. As these beds are indurated, they could not be exploited by placer-mining methods.

FORTYMILE AREA.

The discovery of gold on the Fortymile in 1886 was followed within the next ten years by the discovery of practically all the localities that have since been productive. These include Walker Fork with

its headwaters, Poker and Davis creeks, Wade Creek, Chicken Creek, and small creeks in the vicinity, Napoleon Creek, Franklin Creek, Canyon Creek and tributaries, the Fortymile itself, and a few small areas in the immediate vicinity of the Fortymile. Chicken, Lost Chicken, and Wade creeks yield at the present time the largest annual output of gold. Most of the localities were visited by the writer in 1903, a few of them were reexamined in 1905, and others in 1907. In the following descriptions of the creeks free use has been made of the writer's published statements.[a]

Walker Fork, Poker Creek, and Davis Creek.—The headwater drainage of Walker Fork includes a number of small streams having their sources in the divide within Canadian territory. Of these, Poker and Davis creeks, which carry gold placers, are deeply cut with narrow V-shaped valleys. The grade of the upper part of the Walker Fork valley is approximately 100 feet to the mile. Here the valley floor is a few hundred feet in width, gradually broadening downstream.

A bench about 400 feet high limits the upper part of the valley on the south, and on the north there is a gradual rise to a benched surface at a corresponding level. In the vicinity of Twelvemile Creek there is another bench, about 100 feet high, very prominently developed. The valley narrows and becomes a canyon below the great bend to the northwest about halfway from Twelvemile to the mouth. There is but little timber in the upper part of the valley, and the adjacent ridges are bare. The valley floor and slopes between Cherry Creek and Twelvemile are fairly well timbered, having produced some spruce of sufficient size for mining purposes. There is abundant timber for fuel purposes.

The bed rock of the upper valley is predominantly quartzite schist and carbonaceous schist. In the lower part of the valley there is a large amount of hornblende gneiss with quartzite schist and quartz-mica schist. Between Twelvemile and the mouth of Wade Creek granitic and pegmatitic intrusives are most intimately incorporated with the schists. Dikes and small sills occur from a fraction of an inch to several feet in thickness. These have in many cases been plicated with the schists and even reduced to lenticular fragments. All of these that have been examined under the microscope exhibit the effects of cataclastic action. There are occasional basaltic fragments in the alluvials, and at one locality a fresh basaltic dike was observed. Quartz veins are common, many of them being parallel to the predominant structures. The structure is complex, the attitude being in places nearly vertical and in places horizontal.

[a] Prindle, L. M., The gold placers of the Fortymile, Birch Creek, and Fairbanks regions, Alaska: Bull. U. S. Geol. Survey No. 251, 1905, pp. 39–59.

The first mining was done in the upper part of the valley and on Poker and Davis creeks, the area of economic interest on the Alaskan side extending from the boundary nearly to Cherry Creek, a distance of about 4 miles. In 1907, however, a dredge was installed on Walker Fork about a mile above the mouth of Twelvemile, at a locality several miles below the point where the ground had been found hitherto sufficiently productive to be worked by open cut.

The material on bed rock in the upper part of the valley ranges from 4 to 12 feet in thickness and includes muck, sand, gravel, and in some cases clay. In places there is no overburden of muck and rarely no gravels are found under the muck. The thickness of the gravels generally exceeds 4 feet and the maximum is about 10 feet. The greatest proportion of the gravel is made up of more or less angular fragments of quartzite schist under a foot in diameter. The proportion of bowlders is small. The gold is found not only on the bed rock, but in the gravels above bed rock through a distance of 2 or more feet. It is found also to a depth of 1½ feet or more in the bed rock. Gravel has been worked in places over a width of 50 feet, but on the outer limits it carries only low values. Ground has been worked that is reported to have carried values of $2 or somewhat more to the cubic yard. The general run of gold is made up of small, flat pieces, but nuggets have been found worth as high as $20. Toward the head of the creek there is some gold of a blackish color.

Wade Creek.—The valley of Wade Creek is narrow and V-shaped toward the head, the lower portion is more open and there is a floor a few hundred feet in width that merges finally into the valley of Walker Fork. The fall from the upper limit of placer mining to the mouth, a distance of about 8 miles, is approximately 600 feet. The quantity of water during dry seasons is insufficient to meet the demand. There is considerable timber on the northwest slopes of the valley and a light growth of spruce on the southeast. The valley floor near the mouth of the creek is fairly well timbered with spruce and aspen.

The bed rock in which the valley of Wade Creek has been incised is predominantly schist with some interbedded ferruginous limestone. The schists are in places intruded by granitic rocks, and a small basaltic dike was observed near the head of the creek. Quartz veins are common in the schist. The schist and quartz veins are in places pyritiferous. The gravels range from 1 foot to 3 or more feet in thickness and are overlain by a bed of muck that in places attains a thickness of about 20 feet. Gold is rarely found more than 1½ feet above the bed rock in the gravels. Most of it is on bed rock and in crevices and along joint planes of the bed rock to a depth in places of about 4 feet. The values are rather irregularly distributed. Values were first found on the river at the terminations of the spurs, and these

became favorite localities for prospecting, as the gravel was shallow and the values were frequently greater than in the valley floor.

Much of the gold is coarse and several nuggets have been found ranging in value from $216 to $437. The nuggets are all well worn, contain very little quartz, and are valued at $17 an ounce. The largest of them have been found in the part of the valley about midway between the source and the mouth. The general run of the gold is made up of small flat pieces, and a considerable proportion of that found near the head of the creek is rusty. A small amount of gold has been found in the lateral gulches, and this differs from that in the main creek in being but slightly worn and somewhat rusty. Very little fine gold is found. As so large a proportion of the gold is in the nuggety form and as nuggets are of irregular distribution, the values are extremely variable. The ground is reported to average about $100 to the box length of 12 by 12 feet. The proportion of black sand associated with the gold is small. Barite is abundant, and the rounded pebbles of this mineral are characteristic associates of the gold. Hematite pebbles are also abundant.

The alluvial deposits have been derived from the bed rock of the drainage area. Pieces of gold with quartz attached are common, and an assay of quartz from a vein near the head of the creek was found to carry 0.06 of an ounce of gold to the ton. It seems probable that the gold has been derived from quartz veins and stringers in the schist, and possibly also from mineralized areas in the schists, which are in places impregnated with considerable pyrite.

Mining developments are scattered along about 5 miles of the valley, commencing at a point about 4 miles above the mouth and extending toward the head. The gold is mined principally by open cut, but there is some ground sufficiently deep for drifting.

Chicken Creek and vicinity.—The drainage area of Chicken Creek includes about 20 square miles of a fan-shaped area which is only about 5 miles long from north to south. The tributaries converge from their sources in the divide between it and Franklin and give an amphitheatral form to the upper valley. The creek is a small one, and Stonehouse Creek and Myers Fork are the most important tributaries. The valley of Chicken Creek is open and the lower part has a grade of less than 80 feet to the mile. The valley has a flat on the west, which rises gradually to a broad, low spur, and southward merges into the broad, grassy meadows of Mosquito Fork. The ridge east of Chicken Creek shows a well-defined bench about 275 feet above the creek, where heads a small stream called Lost Chicken, which flows southeast to Mosquito Fork. Ingle Creek, a small tributary of Mosquito Fork about 2 miles west of Chicken Creek and just beyond the western edge of this quadrangle, is included in the productive area.

There is a considerable variety of bed rock in the Chicken Creek drainage area. There are schists in a part of the divide between Chicken and Franklin creeks. Phyllites, limestone, and greenstone occur, all regarded as Paleozoic; there is the northeastern extension of a large area of intrusives, mostly of the composition of quartz diorite, and there is an extensive area of basalt. The general distribution of these rocks is shown on the accompanying geologic map (Pl. V).

The alluvial deposits include the present stream gravels and bench gravels. The stream gravels are of a mixed character. There is a large proportion of greenish hornblendic rock, partly of tuffaceous origin, derived from the large body of this rock present in the hill east of Chicken Creek; there are evenly granular and porphyritic varieties of the quartz diorite; there is vein quartz, phyllite, schist, crystalline limestone and sandstone, coal and ferruginous nodules, which in many cases contain fragments of dicotyledonous leaves. The constituents are mostly under a foot in diameter and the proportion of bowlders is small. The depth to bed rock in the main valley ranges from about 6 to 45 feet. A layer of muck from a few feet to more than 20 feet thick covers the gravels, forming frequently more than half the alluvial deposit. The gravels range from about 6 to 20 feet in thickness and are mostly on the west side of the stream, to a distance of 1,000 feet from it. The lower portion of the gravels contains considerable clay, which often carries away the gold in the sluices.

The pay is found mostly on bed rock, but sometimes extends into it and often above it, where it is found through 5 feet or more of the gravels. Most of the work has been done on the west side of the creek, in places several hundred feet from it. Pay has been found nearly to the western limit of the gravel and over a width of about 80 feet. The values range from $50 to $175 to the box length, and a considerable portion of the ground has probably averaged about $1 to the square foot. The gold is rather fine, and much of it is granular. It is generally dark in color and some of it has quartz attached.

The bench between Chicken and Lost Chicken creeks is about 275 feet above the valley. Claims were located on this bench at the head of the Lost Chicken in 1901, and values were found at a depth of 33 feet. Further prospecting resulted in the discovery of ground carrying values of about $1 to the square foot of bed rock. A 45-foot hole was sunk through 23 feet of muck and 22 feet of gravel similar in character to the stream gravels, but somewhat finer and more rounded. The bed rock is similar to quartz diorite in character, like that at the head of Chicken and that on Mosquito Fork, where gold has been found in the bed rock. The discovery of gold on this bench led to great activity in bench prospecting throughout the region, but up to

1907 this was the only bench found to contain values workable under existing conditions. During 1907 values were found in bench gravels at a locality near the head of Chicken Creek, known as the Last Chance. The deposits at this locality are 18 to 20 feet deep and consist of 10 feet or more of muck overlying a thin bed of gravels resting on a hummocky surface of decomposed basaltic bed rock. These gravels are apparently on about the same level as those of the Lost Chicken bench. Insufficient work has been done to determine the extent of the values.

On the spur east of Stonehouse Creek, about 1 mile north of the junction of Stonehouse and Chicken creeks and about 500 feet vertically above the junction, gold has been found in place in dark phyllites lying on a surface of fine-grained quartz diorite porphyry dipping about 25 degrees. The only exposure at this point is in a hole 10 feet deep which has been sunk through the phyllite and about 2 feet of the underlying igneous rock and in a crosscut which has been carried to a distance of about 35 feet. In immediate contact with the igneous rock is about 10 inches of soft black material having the consistency of clay. The phyllites contain many thin calcite veins and some quartz veins; the thickest observed were hardly more than 2 inches in thickness. The quartz veins contain considerable pyrite, and the thinner calcite veins contain granular pieces and thin plates of gold. The alluvials on the slope below this locality adjacent to Stonehouse Creek, and those in Irene Gulch, which heads in similar phyllites only a short distance from this locality, have been mined for several years, and it is reasonably sure that a part, at least, of the placer gold found has been derived from these mineralized phyllites. The distribution of these rocks has not been determined in detail, but they have been found at several localities on both sides of Stonehouse Creek, where prospect holes have been sunk. The rock outcropping about the head of the Stonehouse is quartz diorite, and it is probably in the vicinity of the contact of this rock with the phyllite that the mineralized areas occur.

The problem of the immediate origin of the gold in the stream gravels of Chicken Creek and its tributaries is complicated by the facts that auriferous bench gravels occur in a part of the valley and that, besides the occurrence of gold in place in the phyllites, gold has also been found in place in the quartz dioritic rock like that forming much of the ridge at the head of the Chicken; but the only locality at which it has been found in this rock lies just beyond the drainage area of Chicken Creek, about 2½ miles up Mosquito Fork.

At this point Mosquito Fork is limited by a steep canyon wall of the quartz diorite, and about 200 feet above the stream is a mineralized zone about 6 feet thick striking approximately N. 25° W., which is very conspicuous by the brilliant red and yellow colors produced by

weathering. The rock has been brecciated and there has been considerable silicification. The surface rock within the zone is thoroughly decomposed and contains abundant fragments of quartz, which occurs in thin intersecting veins. This decomposed material yields fine flour gold by panning. Two assays of material collected in 1903 gave, in fine ounces per ton, for the one, gold 0.58, silver 0.10; for the other, gold 0.36, silver 0.10, or an average per ton of about $9.70 in gold. Since that time a small amount of drifting has been done and higher values have been reported, but no systematic work has been undertaken, and the extent of this occurrence has not been determined.

At a few localities on Chicken Creek, on Myers Fork, on Stonehouse Creek, and on Irene Gulch claims are worked by open cuts. The bed rock on Myers Fork is mostly basalt, and the gravels, from 8 to 20 feet in thickness, are composed largely of coarse fragments of this rock. Most of the gold is on bed rock and is coarser than the average of that on Chicken Creek. On Stonehouse Creek, where work has been done, there is a thickness of about 14 feet of gravels, of which about 4 feet carries values. Irene Gulch is a very small tributary of Stonehouse Creek and the gravels are shallow. While the creek heads in the phyllites above referred to, the bed rock near the mouth is slightly consolidated sandstone containing ferruginous nodules with plant remains. At all of these localities the water supply is limited.

On Chicken Creek most of the ground is suitable for drifting and considerable work has been done. Indeed, much of the ground that it would pay to work under present conditions has been already mined out, and, furthermore, the ratio of water to gravel in the Chicken area is so small that during a large part of most summers work is at a standstill. Several plans to bring water to the gravels of Chicken Creek from Mosquito Fork have been under consideration at different times, and during the summer of 1907 a dam was being constructed at Kechumstuk with that end in view.

Ingle Creek, a small tributary of Mosquito Fork west of Chicken Creek, just beyond the western limit of this quadrangle, has been mined to some extent. The gravel that was being worked here in 1907 was about 4 feet thick, and all was shoveled into boxes. The bed rock at this locality, like that from which a large proportion of the gravels of Chicken Creek has been derived, is mostly a green tuffaceous rock, and here it shows considerable mineralization with sulphides.

Napoleon Creek.—The valley of Napoleon Creek is deeply sunk below the steep slopes, and the valley floor is narrow, being about 300 feet wide at the mouth of the creek. The drainage area is small and the water supply is therefore limited. The valley, like that of Chicken Creek, has a variety of bed rock. The upper part of it is

cut in schists intruded by granitic rocks. In the lower part of the valley are Paleozoic rocks (Devonian?), principally greenstones and limestones, and fragmental rocks ranging from sandstones to conglomerates, regarded as Kenai (Eocene). There is also fresh basalt like that of Chicken Creek, and this occurs probably as dikes in the older rocks. Nearly every year since 1898 a small amount of work has been done on Napoleon Creek, and during 1907 work was in progress on Discovery claim and claim 1 above. The average depth to bed rock at the locality is about 11 feet. The ground ranges from 3 to 10 feet in thickness, and the width of workable ground is about 100 feet. The gold is practically all in the bed rock. It is coarse and of high grade, being reported to assay somewhat in excess of $19 to the ounce.

Franklin Creek.—That part of the valley of Franklin Creek adjacent to the Fortymile is narrowly V-shaped, with a stream flat of very limited extent, in places hardly 50 feet in width. The valley of the upper part of the creek is more open. The quantity of water carried by the stream is so small that in dry weather the water merely trickles through the gravel or stands in disconnected pools.

The bed rock includes micaceous, garnetiferous, and hornblendic schists and crystalline limestones that strike nearly east and west. They show much crumpling locally and are cut in places by granitic dikes. The gravels consist of more or less angular fragments of schist, crystalline limestone, granitic rocks, dark, heavy, rounded pieces of basalt reported to outcrop in the upper part of the valley, and brown and green pieces of rock composed of garnet, epidote, and quartz with considerable pyrite. The depth to bed rock ranges from 2 to 30 feet, with an average of 8 to 10 feet. Pay gravel is found mostly near bed rock and across the entire width of the creek bottom near the mouth, and some of the ground is reported to have carried as high as $5 to the cubic yard. Most of such ground, however, has been worked out. Of two of the largest nuggets found on the creek, one was worth $239 and the other $500. Much work was done on Franklin Creek in the early days, and at the present time it is affording a living to several miners, who are working partly by open cut and partly by drifting.

Canyon Creek and its tributaries.—The lower part of the valley of Canyon Creek is rather open, with a valley floor up to nearly a half mile in width. The valley is deeply sunk below the inclosing ridges, and the valleys of the tributaries are acutely V-shaped. The bed rock includes schists and limestones intruded by granitic rocks and greenstones partly fragmental in character. Considerable work has been done on Squaw Gulch. The stream is small, with a grade of about 150 feet to the mile. The gravels are predominantly quartzitic schist and crystalline limestone, with some granite and vein quartz

ranging in thickness from 3 to 10 feet. The proportion of bowlders is rather large. Gold has been found in about $1\frac{1}{2}$ feet of gravel over a width of about 50 feet. It occurs as small flat pieces, with a considerable proportion of fine flaky gold; but coarse pieces have been found, up to nuggets worth as much as $43. The creek is reported to have produced a total of a few thousand dollars. Work has also been done on Camp Creek and Woods Creek, but the results attained are not available. The valley of the main creek has a large body of gravels, to which attention has been directed during the season of 1907 with the object of working the ground on a large scale.

Gold has been found in place in the ridge south of Kalamazoo Creek, a tributary of Canyon Creek, that heads in Steele Dome. At this locality there is a conspicuous outcrop of vein quartz and quartzitic schists about 1,000 feet in length and 50 to 100 feet or more in width. The rock is partly brecciated and cemented with ferruginous material. Specimens have been obtained showing specks of fine gold. It is not known, however, whether the gold is uniformly distributed through the rock or whether it is only of local occurrence. Placer gold found in creeks draining this area is believed by miners to have been derived from this locality.

Bars and benches of the Fortymile.—Many of the bars of the Fortymile proved very productive in the early days, and even in 1907 a few miners were found making wages with the rocker. The Fortymile follows a meandering course in a steep-walled canyon and, swinging from side to side, has left at more or less regular intervals considerable areas of the bed rock that have been reduced by the stream to a more or less level surface. The bed rock is predominantly closely folded, thin-bedded schists and crystalline limestone. The main structures are generally transverse to the course of the creek, and the attitude is for the most part nearly vertical. The process of downcutting is still in progress and bed rock is exposed along a great part of the stream in this quadrangle.

The bed rock on some of the bars slopes gradually from the stream, leaving an area several hundred feet in width at a distance of but a few feet above it. The thin mantle of gravels with which such areas were covered was easily removed and the cracks and crevices of the broken bed rock, composed of alternating soft and hard layers which afforded an excellent surface for retaining the gold, was most thoroughly cleaned by the miners. At the present time there is renewed interest in these shallow deposits that are under water at certain stages, and they are being investigated with reference to dredging. Where the Fortymile is sufficiently shallow it is possible in winter to sink holes through the ice to the frozen gravels and through them to the underlying bed rock without being troubled greatly by water. The gravel-covered flats that extend back from

the stream a distance ranging from a few hundred feet to half a mile or more are also being prospected.

The flat at the mouth of O'Brien Creek was being mined to a small extent in 1907 and was reported to carry some gold.

Work was being done in 1907 on gravels adjacent to the Fortymile at a locality on the right bank 1 mile above Canyon Creek. The depth to bed rock is from 18 to 22 feet. The gold is mostly on bed rock and to a depth of 1 to 2 feet within it. Water from adjacent creeks was stored in a small reservoir at a sufficient height above the gravels to afford a small head for the utilization of the water by means of a canvas hose and nozzle.

Discovery Bar, about 2 miles below Canyon Creek, was being worked by water from Discovery Creek, conveyed by a ditch about 4,500 feet long. One man was working at this locality with a portable set of short, narrow sluice boxes. The bar is reported to have yielded in the early days approximately $80,000 in gold.

The bar opposite the mouth of Smith (Davis) Creek was being worked in 1907 by water brought from Smith Creek. By taking water from a point about 7,000 feet up this creek a head of 120 feet is available, and two sluice heads are reported as the lowest amount. The water is piped across the Fortymile by means of a cable bridge having a span of 280 feet. The bar was first worked in 1887, and is reported to have produced in the early days approximately $500,000.

Another bar upon which much work was formerly done is located a mile above Moose Creek. In 1907 plans were being carried out to bring water to this locality, a distance of 3 miles, from tributaries of Moose Creek, by means of a combined ditch and flume. The amount of fluming necessary is approximately 7,000 feet. It was expected that 100 to 125 inches of water would be delivered with an available head of 100 feet. The deposit to be worked is 25 feet thick, the gravel being overlain by 6 to 9 feet of muck. The auriferous part of the deposit is 16 to 18 feet thick, half gravel and half broken bed rock. The muck was to be ground sluiced away and the rest of the deposit run through the boxes.

The gravels found on the benches of the Fortymile have in places been found auriferous and considerable attention has been directed to them. It is a slow process to prospect these deposits, and in many localities there is no available water. With the exception of the bench deposits of the Chicken Creek area, already described, no bench deposits have been worked extensively.

There has been considerable prospecting on the benches, and during the summer of 1907 bench deposits on the north side of the Fortymile about 2 miles above Steele Creek, in the drainage area of Flat Creek, were under investigation with reference to working by the hydraulic method. By the construction of a small reservoir and ditch

a small amount of water was made available, sufficient for testing the values to a certain extent. At this locality there is an overburden of 6 to 10 feet resting on about the same thickness of gravel. Work was being done at this locality, so far as the conditions would permit, and values were reported.

The stream that formerly occupied the old valley of the Fortymile, which is so perfectly preserved as the present high bench, was doing work similar to that which is now being done in the present valley. The older valley was wider than the present valley, the processes of concentration had extended over a longer interval of time, and if there was available at that time any considerable body of auriferous material the gold would have been concentrated in such localities as the form of the old valley, the position of the stream within it, and the character of the bed rock rendered most favorable. The amount in the bench gravels at the present time would represent the difference between that originally concentrated in the older valley and that reconcentrated from that older valley into the benches of intermediate height and into the valley of the present stream. Whether such amount proves to be of economic importance is a problem for the future.

Other localities.—There are a few localities where mining has been done that are of interest with reference to the distribution of the gold. Nugget Gulch, a short distance below Steele Creek, is an acutely V-shaped valley that is reported to have yielded in the past several thousand dollars. The stream floor is very narrow and has been worked for about a mile above the mouth over a width of about 30 feet. The valley is cut in an area of schists, limestones, and basic intrusives, and the gravels are similar to those of the other creeks.

The occurrence of gold on Miller Creek, a small tributary of Dome Creek, carries the extent of the possibly auriferous area to a considerable distance north of the Fortymile. Gold was discovered in 1893 and a small amount of work has been done. The bed rock is schist and the gravels are predominantly of the same material. No gold has been found in the other tributaries of Dome Creek or in Dome Creek itself, except immediately below the mouth of Miller Creek. The occurrence is apparently an isolated one.

EAGLE AREA.

The most important gold-producing area in the vicinity of Eagle is that of American Creek and its tributary, Discovery Fork. These streams flow in acutely V-shaped valleys with a rather steep grade. The heads of the valleys are cut in carbonaceous schists and limestones. The bed rock of the lower parts of the valleys is mostly serpentine with basic dikes. The gravels are shallow—up to about 10 feet in thickness.

American Creek has been worked for several years and has produced a considerable quantity of coarse gold. In 1903 preparations were made to work the gravels on a large scale by the hydraulic process. A flume 7,200 feet in length, with a capacity of 1,200 miner's inches, was built and a hydraulic elevator installed. The quantity of available water, however, was limited and the plant could not be used to best advantage. On Discovery Fork an automatic dam had been constructed and found to work successfully, and in 1907 preparations were being made to work the ground on American Creek by the same method. The construction of the government wagon road by the road commission has brought these localities into close relation with Eagle, only about 10 miles distant.

SEVENTYMILE AREA.

The valley of Seventymile Creek as far as the falls is located mostly in Kenai (Eocene) conglomerates. Above the falls as far as Barney Creek the Seventymile flows close to the contact of the Kenai rocks with schists. The valley is elaborately benched, and the surface of the lowest bench, about 20 feet above the stream, is covered with gravels several feet in thickness that are being prospected for working on a large scale. At the falls, about 20 miles from Eagle, the bench gravels have been mined to some extent and some gold has been extracted. Most of the mining, however, has been done on tributaries of the Seventymile, and those that have proved productive within the quadrangle are Broken Neck, Sonickson, and Nugget Creek.

Broken Neck Creek enters the Seventymile from the north, just above Mogul Creek. The Valley is deeply cut in Kenai conglomerate and shales, and where the stream leaves it the valley floor is only about 120 feet wide. The rocks dip 75° to the north and the shales contain many fossil leaves. The gravels are composed of the pebbles found in the conglomerate, pieces of shale and sandstone, a small proportion of quartzitic bowlders a foot or more in diameter, unlike the constituents observed in the conglomerate at this locality, and large bowlders of compact, fine-grained conglomerate, composed largely of chert pebbles. The creek has been worked to a width of 100 feet from the north to a point about half a mile upstream. The pay streak is reported to have been about 6 feet wide.

Sonickson Creek flows in a canyon whose slopes exhibit well-defined benching near the Seventymile. The bed rock at the mouth is a calcareous schist. The gravels contain bowlders of schist, conglomerate, greenstone, and granite. A small amount of work has been done near the mouth, but the results thus far obtained have not proved very encouraging.

Barney Creek enters the Seventymile from the north. The valley near the mouth is a very narrow cut in conglomerate and shales that range in dip from 55° S. to vertical. The gravels in the creek bottom are from about 1 to 3 feet thick and are composed of pebbles from the conglomerate, pieces of bowlders, and vitreous quartzite up to 3 feet in diameter. At a level of 50 feet above the mouth of the creek are bench gravels about 6 feet thick resting on the edges of the upturned conglomerate. These contain large quartzite bowlders like those observed in the creek gravels and similar also to those observed in Broken Neck Creek. These bench gravels on Barney Creek are auriferous and it is probable that part, at least, of the gold in the creek gravels has been derived by reconcentration from them.

The occurrence of gold on Nugget Creek and Flume Creek, both tributaries of the Seventymile to the west of the Fortymile quadrangle, indicates the extension of the auriferous area westward.

In conclusion it may be said that a few of the tributaries of Seventymile have produced in the past fairly good pay, Barney and Broken Neck creeks having been most productive, with several thousand dollars probably to the credit of each, and that there are extensive deposits of gravel along the main stream that in places have been found auriferous.

MINING METHODS.

Mining in the Fortymile quadrangle has been done by the rocker, by open-cut work, by hydraulic methods, by drifting, and, during the season of 1907, by dredging. Various accessory means for the utilization of water have been brought into service, such as ditches, small reservoirs, automatic dams, etc.

Much work was formerly done by the rocker on the bars of the Fortymile, and even in 1907 a few instances of reversion to this original type were observed. The prevailing low stage of water was especially favorable for this kind of work. With the exception of the mining on Chicken Creek, most of the work has been done by open cut. The ground is generally stripped first of all by ground sluicing; then a cut of sufficient width for one or two sets of boxes is opened, and a bed-rock drain several hundred feet in length is constructed. The pay gravels have generally been shoveled into the boxes by hand work, but steam scrapers and bucket conveyers have also been used for this purpose. The hydraulic method has been used only to a small extent. Drifting is the most common method in the valley of Chicken Creek. The process includes the sinking of a shaft to bed rock, a distance of 20 to 40 feet, the timbering of the shaft, the opening up of the ground by drifts from which crosscuts are driven, the extraction of the few feet of auriferous gravels, and the hoisting of this material to the surface, where the gold is recov-

ered by ordinary sluicing. The method of thawing by steam points is the one most commonly employed.

The most recent development of method in the Fortymile region has been the introduction of dredging. The season of 1907 was an experimental one for this method, and while the results were perhaps incommensurate with the expectations, a considerable body of experience was undoubtedly acquired regarding the conditions under which dredging has to be carried on in this region. A dredge was installed an Walker Fork, about a mile above the mouth of Twelvemile, in the spring of 1907; a dredge was in the process of construction on Pump Bar of the Fortymile, about 2 miles below the mouth of Franklin Creek, during the summer of 1907; a dredge was in operation on the Fortymile at the Boundary, and another was working Sour Dough Bar of the Fortymile about 4 miles above the mouth, in Canadian territory.

The dredge on Walker Fork was freighted up the Fortymile and Walker Fork to its present position during the winter of 1906–7. The valley floor where the dredge is located is several hundred feet wide. The bed rock in this part of the valley includes schists, gneisses, and granitic intrusions, partly parallel with the main structures and partly cutting them. The alluvial deposits are reported to range from 6 to 14 feet in thickness, with an average of about 9 feet. The muck ranges from $1\frac{1}{2}$ to 4 feet in thickness. The gold is said to be mostly on bed rock or within it to a depth of a few inches. The deposits are frozen. Insufficient ground had been previously prepared by ground sluicing for the operation of the dredge and it was necessary to use steam points for thawing the gravels. The dredge is a bucket open-connected steam dredge, the buckets having a capacity of 5 cubic feet. It was reported capable of working about 3 acres a month to a depth of 14 or 15 feet. The dimensions of the dredge are 36 by 76 feet and it draws about $4\frac{1}{2}$ feet of water. It was held in position by two cables on each side and one in front, all held by deadmen. Three men are required to run it—a winchman, an engineer, and a fireman. The working season can commence from the 10th to the 15th of May and continue till the middle of September, giving about 120 days. The great difficulty encountered is the frozen character of the ground. It has been found necessary to prepare ground by stripping at least a year in advance in order to give the greatest opportunity possible for thawing by natural processes and thus for saving to a great extent the extra expense of thawing by steam points. Bucket lips that have a life of perhaps nine months under such conditions as are found in the dredging areas of California are worn down completely in a few weeks where they have to encounter frozen ground.

The machine in process of installation on Pump Bar below the mouth of Franklin is a dipper dredge. The machinery had been freighted up the Fortymile and was being assembled on a scow 42 by 80 feet, built of native spruce lumber. The capacity of the dipper was $2\frac{1}{2}$ cubic yards and the machine was expected to handle about 1,000 cubic yards in ten hours. The ground to be worked is a shallow portion of the bed of the Fortymile, ranging from 6 to 12 feet in thickness, and is all unfrozen. It was reported that ground carrying 25 cents to the cubic yard would pay the cost of working.

The dredge on the Fortymile at the boundary is similar to that of Walker Fork but of less capacity. It was working on a bar of the Fortymile where the average depth to bed rock is about 8 feet. While bowlders are somewhat troublesome there, necessitating frequent stopping of the machine, the ground is for the most part unfrozen.

The dredge on the Canadian side of the boundary is a much larger machine with a capacity of 3,000 cubic yards per day, and a capacity for depth of 35 feet. This dredge also was working on a bar of the Fortymile where the ground was unfrozen and the bed rock soft.

There are many factors to be taken into consideration in any plan involving the installation of a dredge, and the neglect of any one of them may be fatal to the success of the undertaking. This is not the place for a detailed statement of the dredging problem, but inasmuch as some of these factors are overlooked so frequently with apparent indifference by those in charge of operation attention may be drawn to some of them. There is, for example, the problem of the determination of values in the ground. It might seem superfluous to insist on the importance of a thorough preliminary investigation of the ground, but those familiar with the conditions will recall cases where this vital factor has been practically neglected. There are also to be considered the dimensions and character of the alluvial deposits, the vertical and horizontal distribution and the character of the gold; the bed-rock surface, its hardness, receptivity for gold, and adaptability for dredging; the water and fuel supplies; the length of the working season; the costs of material, labor, and transportation; and the selection of a dredge best adapted to the conditions presented by the ground under consideration.

PRODUCTION.

The production of placer gold of the Fortymile quadrangle, inclusive of 1907, has been approximately $5,000,000. Most of the gold is taken out of Alaska by way of Fortymile River, and from records furnished the Survey by the office of the United States Customs Service at the subport of Fortymile, Alaska, the following table showing the production of the Fortymile area for the years 1904 to 1907 has been prepared. These statistics do not include the pro-

duction from the Eagle and Seventymile areas, for which very incomplete data are at hand. The production of the entire Fortymile quadrangle for 1907 was approximately $150,000.

Production of the Fortymile area for the years 1904 to 1907.

Creeks.	1904.		1905.		1906.		1907.	
	Fine ounces.	Value.	Fine ounces.	Value.	Fine ounces.	Value.	Fine ounces.	Value.
Chicken, Lost Chicken, Myers Fork, Stonehouse, and Ingle.	6,819.74	$140,964	5,368.11	$110,959	4,269.32	$88,247	2,377.74	$49,147
Franklin	494.29	10,217	581.47	12,019	783.79	16,201	100.34	2,074
Wade	5,233.24	108,171	4,521.00	93,449	3,094.87	63,971	3,381.90	69,904
Walker Fork, Poker, and Davis	1,222.11	25,262	1,124.28	23,239	1,184.32	24,480	484.42	10,013
Squaw, Camp, and Woods Canyon	156.27	3,230	103.62	2,142	63.32	1,309	123.36	2,550
Napoleon, Montana, Buckskin, Dome, Eagle, and Twin	51.00	1,054	46.06	952	13.11	272	11.51	238
Fortymile bars and commercial dust	886.60	18,326	637.40	13,175	437.54	9,044	266.47	5,508
	14,863.25	307,224	12,381.94	255,935	9,846.27	203,524	6,745.74	139,434

SUMMARY.

The topographic features of this quadrangle comprise numerous ridges, of approximately uniform height, separated by deep, relatively narrow valleys. The rocks include a complex of schists and limestones with altered intrusives; Paleozoic phyllites, quartzites, limestones, and greenstones, both intrusive and extrusive, with associated tuffs; Tertiary clays, lignite, sandstone, shale, and conglomerates; bench gravels and stream gravels; and unaltered igneous rocks. The structure is exceedingly complex. The dominant trends in the northern part of the quadrangle are northwest-southeast; in the southern part, northeast-southwest to east-west. Igneous rocks are abundant and have been an important factor in the geologic history. The gold deposits are probably to be referred indirectly to them. The age of mineralization is not definitely established, but some of the auriferous material originated subsequent to the intrusion of comparatively fresh granular rocks of intermediate composition, which may have been as late as the Upper Cretaceous.

The quadrangle has produced approximately $5,000,000 in placer gold, and while the decreasing annual production indicates that the ground which it would pay to work under present conditions will soon be exhausted, there are still considerable bodies of low-grade ground that, under a lower cost of mining due to improvement in the facilities of transportation and cheaper methods of handling material, could probably be profitably mined. No workable deposits of coal have been found, but a small amount of local coal has been used for blacksmithing purposes.

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O

Datum is mean sea level
based on observations at Dawson and
Camp Davidson on Yukon River as established by
U.S. Coast and Geodetic Survey in 1898

TOPOGRAPHIC RECONNAISSANCE MAP OF FORTYMILE QUADRANGLE

Scale 1 inch = 2 miles

Contour interval 200 feet

1908

GEOLOGIC RECONNAISSANCE MAP OF FORTYMILE QUADRANGLE

Scale 1/250000

miles

kilometers

Contour interval 200 feet

1908